A KANSAS HAZARDOUS MATERIALS TRANSPORTATION RISK AND VULNERABILITY ASSESSMENT TOOL

Project Final Report

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TABLE OF CONTENTS

List of Tables

List of Figures

List of Appendices

A Kansas Hazardous Materials Transportation Risk and Vulnerability Assessment Tool

Abstract

The shipments of hazardous materials are of great concern, although the data available on the transportation of these materials is insufficient and sometimes inconsistent. The National Transportation Safety Board (NTSB) has reported that more than 500,000 shipments of hazardous materials move daily through the U.S. transportation system through different modes. *(1)* Approximately 10,000 to 20,000 truck transportation incidents and roughly 1,000 to 1,500 rail incidents occur each year that involve release of a hazardous material or a circumstance that threatens a release and to which public-sector emergency responders are dispatched. *(2)*

Every state is required by law to develop an emergency response plan. An essential element to emergency response is the determination of the patterns of the movements of hazardous materials within the state and the location for the placement of response teams. This report presents the development of a statewide model to assess risk and vulnerability on a county-by-county basis. The model determines relative risk among counties for transportation of hazardous materials on all modes and supports decisions associated with placement of response resources in the state.

The Risk Factor components considered in the anlaysis were highways, railroads, pipelines, waterways, airports and fixed facilities. The components for the Vulnerability Factor were population density, environment, land use, water treatment plants and special

facilities (hospitals, nursing homes, schools, prisons and stadiums). A Risk Index, a product of Risk Factor and Vulnerability Factor, was calculated for each county.

A MapInfo™ application (KRISP) was developed to manage the extensive data required in this model and to calculate all components of the Risk Analysis. Numerous advantages of using the geographic information system (GIS) approach were identified. GIS allows for development of the risk model equations, updating the model with new data and interpretation of results. The results of the Risk Analysis displayed graphically in the GIS environment identified potential areas for locating regional hazardous materials response teams.

References

1. *Logistics for Hazardous Materials Transportation: Scheduling, Routing and Siting*, Interim Report, US Department of Transportation, Washington. D.C., June 1990.

2. *Hazardous Materials Shipment Information for Emergency Response*, Special Report 239, Transportation Research Board, Washington, D.C. 1993.

CHAPTER 1

INTRODUCTION

1.1 Background

Hazardous materials from gasoline to explosives to radioactive materials are important to the economy of the country and must be transported; but the risks involved in transporting these materials must be minimized and acceptable. The demand for the production and eventually the transportation of these materials are directly proportional to the industrial growth of the country. At the same time, it becomes essential to protect the people and also the environment. Risks associated with hazardous materials incidents have drawn considerable attention, both nationally and internationally. The importance of these risks has prompted the introduction of local, national and international regulations in an effort to ensure safe transport of a wide variety of materials. A statewide program is essential to minimize the hazards associated with transportation of hazardous material.

The shipments of hazardous materials are of great concern, although the data available on the transportation of these materials is insufficient and sometimes inconsistent. The National Transportation Safety Board (NTSB) has reported that more than 500,000 shipments of hazardous materials move daily through the US transportation system through different modes. (1) Approximately 10,000 to 20,000 truck transportation incidents and roughly 1,000 to 1,500 rail incidents occur each year that involve release of a hazardous material or a circumstance that threatens a release and to which public-sector emergency responders are dispatched. (2)

The Hazardous Materials Transportation Act of 1975 (HMTA) and its reauthorization legislation, the Hazardous Materials Transportation Uniform Safety Act of 1990 (HMTUSA), section 1801, P.L. 101-615 (3) define a hazardous material as a substance or material in a quantity and form that may pose an unreasonable risk to health, safety or property when transported in commerce. Hazardous materials pass through large cities, small rural communities and open lands twenty four hours a day. Accidents involving these hazardous materials can occur at any place. Fire fighters and police often must respond to these incidents. Dealing with such an incident requires knowledge of the nature of the material, otherwise it would complicate the incident and may result in fatalities. Emergency response personnel and the public in local communities need to know the risk to which they are exposed and understand the potential dangers. Guidelines to develop an organizational structure for an emergency response plan and training program geared to their particular level of risk are essential to minimizing risk.

Section 1815 of the Hazardous Materials Transportation Uniform Safety Act of 1990 (P.L. 101-615) made funds available to Kansas and other states to develop, improve and implement emergency plans which included the determination of the patterns of movements of hazardous materials within the state and to determine the need for regional hazardous materials emergency response teams. This project has developed a microcomputer-based tool to assess risk and vulnerability on a county-by-county basis. This tool provides information upon which to begin to base decisions for placement of response teams. It is the responsibility of the state to see that emergency response capabilities be strategically distributed to provide the most efficient and effective response capability. Hence, an analysis of resource distribution must be based on relative assessment of risk and vulnerability among regions of the State of Kansas. This model assesses the risk that exists in the counties with regard to exposure to hazardous materials and identify the vulnerable zones in terms of population, environment and other facilities.

1.2 Literature Review

Over the last decade, there have been significant advances in the methods for assessing risks associated with the transportation of hazardous materials along a specified route. Many models have been developed both locally and nationally in this regard. The review of these models provides a solid foundation for the development of new ideas to construct a model appropriate to Kansas needs and other states interested in strategic location of resources. An attempt was made to identify existing models used or in development in other states. A review of the literature and a request sent to approximately twenty-five state departments of emergency preparedness yielded information on two basic approaches: community-level and route-level risk assessment models.

Community-Level Risk Assessment Models

Community-level risk assessment models predict risk and vulnerability to which local community is exposed and would indicate the level of preparedness necessary for that community. The models may be either mode specific, i.e., limited to a specific mode of transportation alone or may consider different modes of transportation.

The *Kansas State Model* was developed for individual communities for handling hazardous materials transportation emergencies. (4) This is a simple model intended for use in communities whose population is less than 50,000. The Risk Index is calculated as a product of risk factor and vulnerability factor. Calculating the risk index requires commodity flow studies, obtaining vehicle and placard counts displayed by transporters of hazardous materials. Using weighting factors for size of vehicle and hazard class, an adjusted placard count is derived and converted to an average threat value. The risk factor is the product of average threat value and daily placard carrier count. Risk factors are calculated for different modes like highways, railroads, pipelines, waterways and airways.

This model provided guidance for estimating vulnerability to be used in our model. The vulnerability or the consequence factor is composed of four sub-factors: population density, land use, natural resources and manufacturing and storage establishments. As the importance of each sub-factor increases, a higher numerical value is assigned. The number of business handling hazardous materials, their proximity to other such establishments affect the manufacturing and storage establishments sub-factor.

The Kansas State model's approach is a good contribution although it is not theoretical in nature. Risk factor is based on an average form of threat and traffic density. It is difficult to calculate the hazardous material carrying traffic volume, particularly statewide, since those data are not currently available. Simplicity and reasonableness were the chief criteria in developing it and provided a useful starting point.

The Zaizic and Himmelman Model provides a population and environmental rating scheme and a maximum disaster potential index for communities. (5) This model was developed for a Canadian city of 60,000 population.

The community rating system attempts, through a series of empirical formulae, to determine the risk to population and environment based on analysis of three different modes - highway, rail and water- and industrial and storage facilities. The disaster rating was based on the area affected by potential hazardous material incident and the maximum population density along the transportation route or adjacent to an industry.

The population hazard rating (HP) is given by:

$$HP = HP_H + HP_R + HP_m + HP_{IND} + HP_{ST}$$

The environmental hazard index (HE) for the assessment area is given by:

$$HE = HE_H + HE_R + HE_m + HE_{IND} + HE_{ST} + HE_P$$

where, the subscripts H, R, m, IND, ST and P stand for highway, railway, marine, industry storage and pipeline respectively. Each of the above indices are given by several formulae.

The community hazard rating calculation requires input variables of number of vehicles, percentage of vehicles carrying hazardous materials, average traffic density, population density, type and quantity of material carried and length of pipeline. Some of the underlying principles associated in establishing the risk factor in the Zaizic and Himmelman Model were considered in Kansas model. For example, the risk factor as a product of traffic density and the quantity of material carried was incorporated in to this model.

Route Level Models

The routing models revealed by the literature were limited to a single mode of transportation, either highways or railroads and help to determine the best route among several alternative routes considered. Identifying the safest routes is done either by minimizing the potential for accidents by selecting a route with lowest accident rates or by minimizing the consequence of an accident by selecting a route with lowest adjacent population densities.

The University of Nevada identified Nevada highway routes that could be used to transport current shipments of radioactive materials and high level radioactive waste. (6) The study examined several existing routing and risk models to determine their suitability to select routes that minimize risk to public. Each model was tested by analyzing three alternative routes, and based on this analysis, a routing model *StateGEN* was selected to identify the alternate routes between two specific points.

StateGEN allows the user to create a network of roads. The user specifies origin and destination points on the network, and the parameter to minimize. Twenty-eight parameters were identified including traffic characteristics, geometrics, special facilities and environment and population density. The assessment of risk to transport radioactive materials involves two important factors: probability of accidents and gravity of consequences in the event of an accident. Identifying alternative routes in Nevada involved identifying accident rates and population densities. The best route minimizes truck accident rates, population densities and distance.

Nevada's study was conducted to find the best highway route with no effort to identify risk of transport of hazardous materials on any other modes. However, the parameters developed for testing the model provided a foundation for developing the risk model for the state of Kansas.

The *Raj and Glickman Model* generates a risk profile for rail transportation of any hazardous material on any route. (7) It highlights the risks of accidents involving larger releases (collisions and derailments on main lines and in yards). Risk profiles for various hazardous materials or for various routes can be combined. The approach uses a specially developed model for the probability distribution of the number of cars experiencing a release in such an accident. The effects are combined with the population exposure estimates to estimate fatality levels.

The expected frequency per year of accidents in which a particular hazardous material is released from a given number of cars on a particular route segment I is estimated from the overall expected frequency per year of accidents and the probability that the material is released from that number of cars. The results are then summed over all the route segments. Symbolically,

$$F(I_x) = F_s P_s(I_x)$$

where,

$F(I_x)$ = Expected frequency per year of accidents

I_x = Number of cars that release hazardous materials x

F_s = Expected frequency per year of accidents on segment s

P_s = Probability that I_x cars release x in an accident on segment s

F_s on main-line segments is computed on the basis of accident statistics, traffic volume data and route parameters. F_s on yard segments can be computed from accident statistics and yard activity data.

A sequential approach is adopted in computing the probability distribution which has the advantage that sensitivity analysis can be performed later, by varying any of the probability distributions to represent different accident scenarios. The consequence factor is calculated by multiplying the lethal area of release by the population density.

After studying these models, the various parameters used in developing them and their suitability to Kansas needs are studied. Since the purpose of the model is to develop a relative risk index among counties, it was important to select variables that would provide significant differential among counties of the state. Some of the parameters used in cited models like wind velocity, topographical conditions of the state and gradients of the road were not considered in developing this model since topographical changes among counties in Kansas are moderate. The wind velocity is assumed to be uniform throughout the state. Most of the models studied were limited to a particular mode of transportation. Efforts were made in this project to develop an integrated model which can be used to calculate a risk index for all modes of transportation of hazardous materials.

1.3 Objectives

Over the last decade, there have been significant advances in the methods for assessing risks associated with the transportation of hazardous materials along a specified route. Many models have been developed both locally and nationally in this regard. The review of these models provides a solid foundation for new approaches in developing a model appropriate to Kansas needs. Input from the key state agencies and from any other states was essential in the development of a useful tool. Hence, the first step was to gather information about similar models which have been in use or which are in the process of development in other states. The information gathered provided a foundation for the construction of a Kansas model. The primary goal of the research work was to develop a model and a microcomputer-based software tool for assessing risk and vulnerability involving hazardous materials transportation and accidents among Kansas counties. The specific approach and the areas of principal concern towards developing this model are:

- Study of the pertinent literature on hazardous materials transportation, particularly related to risk and vulnerability analysis;
- Identification of existing models in peer states and feasibility for adaptation to Kansas needs, if any;
- Compilation of data bases from the existing sources and solicit input from state and local emergency preparedness teams;
- Develop a risk and vulnerability assessing model;
- Develop a graphic-driven interactive tool that is easy to use and provides up-to-date statewide management information - GIS application;
- Test the risk analysis model - perform sensitivity analysis.

Certain assumptions were made prior to the development of the model. The first assumption was that input from the key state agencies represented on the Kansas State Emergency Response Commission as well as from selected local emergency response committees will be invaluable to the development of the model that is useful to the Division of Emergency Preparedness.

The second assumption was that data representing the key factors to risk and vulnerability assessments existed in sufficient form within these agencies and that original data collection will not be required to develop the model. However, there is a limitation of existing reporting systems that under-present actual incidents due to non compliance by transporters or inaccurate reporting. Therefore, the model is developed to accept data enhancements as data collection is improved.

The final version of the model is presented in a format that is interactive and easy-to-use by state management and will serve as an on-going management information tool. Application of Geographic Information System (GIS) technology to the model offers a graphical interface to easily communicate relative risk and vulnerability among areas of the state.

Chapter 1 References

1. *Hazardous Materials Transportation Safety Act of 1990*, §1801, P.L. 101-615.
2. *Hazardous Materials Shipment Information for Emergency Response*. Special Report 239, Transportation Research Board. Washington, D.C. 1993.
3. *Hazardous Materials Transportation Safety Act of 1990*. §1801. P.L. 101-615.
4. *Risk Assessment/Vulnerability Users Manual for Small Counties and Rural Areas*. Report #DOT/OST/P-34 / 86-043, USDOT, March 1984.
5. Zajic, J.E. and W.A. Himmelman (1978). *Highly Hazardous Materials Spills and Emergency Planning*. New York: Marcel Dekker, Inc.
6. *The State-Wide Radioactive Materials Transportation Plan, Phase I and II*. Nevada Department of Transportation, December 1989.
7. Raj P.K. and Glickman T.S. (1986). *Generating Hazardous Material Risk Profiles on Railroad Routes*. State of the Art Report 3, Recent Advances in Hazardous Material Transportation Research. Washington, D.C.: Transportation Research Board.

CHAPTER 2

DATA SOURCES AND COLLECTION

2.1 Data Collection Methodology

The peer state data in the form of existing models were collected in three ways:

(a) Review of the literature. A literature survey provided information regarding risk and vulnerability factors in the transportation of hazardous materials. Existing risk and vulnerability models were identified in the state of the art review. An annotated bibliography is provided as Appendix 1.

(b) Direct contact. The Kansas Division of Emergency Preparedness sent letters to various states, requesting them to send any information on procedures or models currently used them for the assessment for risk and vulnerability. Responses received were forwarded to the Transportation Center to be incorporated into the peer state assessment. In addition, agencies within the state responsible for data collection relevant to risk and vulnerability were contacted for additional information. The results of that contact are documented in this chapter.

(c) Meetings. Advisory committee meetings were held throughout the project to provide input to model development. Representatives from different agencies who attended the meeting, provided valuable information with regard to existing models and refinements to

the new Kansas model. Appendix 2 provides a roster of Advisory Committee members and agenda materials associated with the Advisory Committee meetings.

2.2 Peer State Assessment

The Division of Emergency Preparedness sent letters, seeking information regarding the existing models to various states in the United States. Requests were sent to California, Nevada, Utah, Wyoming, South Dakota, Colorado, Nebraska, Iowa, Missouri, Texas, Oklahoma, Arkansas, Tennessee, Illinois, Minnesota and New York. Six states provided input, with ten states indicating that they do not have a program. The states which returned the information requested are Utah, Nebraska, Minnesota, Tennessee, New York and Nevada.

NEW YORK. The New York State Disaster Preparedness Commission provided a copy of a work-in-progress on hazardous material transportation risk assessments entitled *Hazardous Materials Transportation Emergencies : A Planning Guide*. This guide, using credible worst case risk assumptions, provides two simplified approaches to hazardous materials transportation planning. Both approaches assume that generic and fixed-site hazardous materials planning have already been accomplished under the SARA Title III program. This guide does not explain how to proceed with the planning once the risk is identified.

Fixed-state planning focuses on vulnerability zones surrounding facilities with extremely hazardous chemicals. New York State, incorporating the guidance in its SARA Title III planning guide and model plan, developed a computer program for calculating vulnerable zones. Two approaches were used to estimate vulnerable zones, the ***grid approach*** and the ***corridor approach***. These two approaches may be viable to transportation routes.

The grid approach requires dividing the entire jurisdiction into planning areas or zones by means of grids of one square mile. These zones are identified by numbers or letters. Any accident involving materials can be located in the designated zone. All the protective measures are identified for each of these zones. The protective measures include the identification of resident and peak population, special facilities and the evacuation procedures, identification of evacuation routes and identification of public safety agencies with responsibilities for the zone. New York State utilizes the grid approach to inform the public of a hazardous material emergency, in compliance with SARA TITLE III, the *Emergency Planning and Community Right-to-know Act of 1986*. Hence, for these actions to be effective for each zone, the public must know what zone they are in and must be made aware of the evacuation procedure to be followed during an emergency. They must be aware about the special facilities and the evacuation routes in their respective zones. Publishing zone maps in newspapers or in telephone books are methods to provide information to the public. GIS can be utilized to identify all the residences and special facilities in a zone by the address or the name of the owner. Each zone can further be identified by specific hazards that may affect it. If a one mile zone is considered too large, then it can be sub-divided into four quarter-mile zones.

The corridor approach focuses on persons at the greatest risk to a hazardous material transportation accident, those closest to the transportation route. For each route selected, a line on each side of it is drawn at a distance of one-half mile from the route. The actual route becomes the center line for a mile-wide corridor. The corridor is then divided into one-half mile segments. The corridor is comprised of one-half mile by one mile planning zones. Now the approach is similar to that of the grid method.

The New York study is still under progress and no results are provided in the study report.

MINNESOTA. The Minnesota Emergency Preparedness Commission, in response to the request, sent a copy of the study that Minnesota has undertaken. *(1)* The study is still under progress and no results are available yet.

The main objectives defined for the Minnesota study and the procedures adopted to achieve them include:

- Establish a multi-agency technical assistance support group. The technical assistance support group will be developed by identifying key metropolitan and regional agencies and selecting a representative from each agency.

- Identify primary transportation routes through personal interviews and questionnaires sent to different companies transporting hazardous materials.
- Conduct a hazard analysis to identify the hazardous materials transported through a regional market study.
- Conduct a vulnerability analysis of the identified primary transportation routes using the software *CAMEO-II-DOS* and *ARCHIE Systems*, for each of the corridors located within the district.
- Prepare written and mapped descriptions of the identified routes.
- Complete a final report containing all maps and other information identified during the project's course.
- Distribute the summary report to the review committees, state agencies and other key agencies.

TENNESSEE. The State of Tennessee sponsored the development of a software package called *HazPlannER* for its emergency planning needs. This software was developed by Abkowitz and Associates, Inc.(AAI). AAI claims it to be a powerful tool for emergency management planning for hazardous materials within MicroSoft and Windows. *(2)*

HazPlannER addresses the following issues -

- Hazard Identification: Identify and locate hazards within each jurisdiction.

- Emergency Response Coverage: Evaluate the level of emergency response coverage within the jurisdiction and identify areas that do not have adequate coverage.
- Hazard Analysis: Estimate the impact of a potential incident for any given location within the jurisdiction.
- Risk Screening: Screen the facilities within the jurisdiction using different criteria to place the facilities in relative order.

State of Tennessee staff indicate that the package is not being used by the state currently.

NEVADA. The University of Nevada, Reno, has prepared a detailed report in two phases for the Nevada Department of Transportation. *(3)* The first phase is a work plan for the nuclear materials transportation investigation and the second phase is the state wide radioactive materials transportation plan.

The objective of Phase I is to identify the shippers and carriers responsible for the transportation of high level radioactive waste and highway route controlled quantities of radioactive materials through the state. A review of the federal, state and local regulations pertaining to the transport of nuclear materials by highway vehicles is given in the first part of this report. These regulations include the packages and the label requirements, shipping papers and certificates, routing requirements, shipments, training the drivers of the vehicles carrying hazardous materials and disposal of radio active materials. The three agencies significantly involved are the U.S.Department of Transportation (USDOT), the U.S.Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC). The latter part of the report identifies the shippers and carriers using Nevada's highways to transport radioactive waste. It also includes a detailed catalogue of the origins, destinations, dates and nature of material. The source of this information is the USDOT.

Phase II of this study is intended for the identification of highway routes that could be used to transport hazardous materials. The study examines several highway routing and risk models to determine their suitability to select routes that minimize risk to the public. Sources of these models were USDOT, Sandia National Laboratories, Oak Ridge National Laboratory and Pacific North West Laboratory. Each model was tested by analyzing three alternative routes from the California-Nevada border, south of Searchlight to the Nevada test site at Mercury. Based on this analysis, "**State GEN**" was chosen to be used in this study.

Data on safety and infrastructure characteristics of the network of Nevada's roads were collected. This network was divided into 171 segments, which includes Interstate, US and State highways. Twenty-eight highway parameters were identified as useful in the preliminary selection of roads to transport the materials. These parameters are applied to each of the segments of the road. They include information about traffic characteristics, geometrics, special facilities and environment. Most of these data were obtained from Nevada DOT. These parameters are :

- Average daily traffic
- Average daily truck traffic
- Accident rates
- Truck accident rates
- High accident locations
- Number of accidents per location

- Average speed
- Number of lanes
- Shoulder width
- Surface type
- Critical grade
- Critical horizontal curves
- Critical combination of horizontal curvature & vertical grade
- Rail road grade crossings
- Structural capacity of bridges
- Population densities
- Rest areas
- Hospitals along routes
- Fire stations along routes
- Schools along routes
- Annual snowfall
- Annual rainfall
- Time of travel
- Distance
- Wind hazard locations
- Dust hazard locations
- Flood hazard locations
- Pavement condition (rut depth & Present Serviceability Index)

The assessment of risk involves two important factors: (1) probability of accidents and (2) gravity of consequences in the event of an accident. To identify alternative routes, accident rates and population densities were used in the selected model. By modeling four primary parameters (total accident rates, truck accident rates, population density and distance). StateGEN identified several alternative routes from a specified origin to Mercury (destination). These alternative routes are identified by StateGEN, by minimizing the parameters used in the risk assessment. The preferred routes will be finally selected by the Director of Nevada Department of Transportation.

NEBRASKA. Nebraska has not undertaken any formal risk assessment of hazardous materials transported across or within the state. The State has collected the spill data reported to Nebraska Department of Environmental Quality for the past two years and has prepared a summary by county. The Transportation Planning Division publishes a map annually, showing the locations of spills.

UTAH. The State of Utah has neither undertaken any formal study nor has developed any model regarding the assessment of risk and vulnerability in transporting hazardous materials.

A brief summary about the information on procedures or models currently used by various states is given in Table 2-1.

Table 2-1
Peer State Survey
Statewide Risk and Vulnerability Assessment Models

State	Existing model	Work in progress	No model	No response	Comments
New York		x	x		A computer program has been developed to estimate vulnerable zones using grid & corridor approach
Minnesota	CAMEO-II-DOS	x			Conducting vulnerability analysis using CAMEO-II-DOS & ARCHIE systems
Nevada	StateGEN				Uses a report prepared by the University of Nevada, Reno, for identifying the highway routes
Tennessee		x			Even though the software HazPlanner was developed, it is not being used by the state
Nebraska			x		No study undertaken
Utah			x		No study undertaken.
Texas				x	
Indiana				x	

2.3 Data Sources

The data representing the key factors to risk and vulnerability assessments were provided by the key state agencies represented on the Kansas State Emergency Response Commission as well as from selected local emergency response committees. The various types of data needed for developing this model and their sources are listed in the subsequent paragraphs.

RISK ANALYSIS VALUES

Highways

Year(s): 1992

Source: Kansas Department of Transportation Traffic Map

Variables: ADT, ADTT for total traffic and heavy vehicle traffic

KDOT collects traffic count data on all state routes, as well as vehicle classification and weigh-in-motion data from specific sites throughout the state. Aggregate traffic volume data are available for all state and federal routes. Vehicle classification data, in hourly increments, are collected at about 100 sites per year. Weigh-in-motion data, including types of trucks, are collected at about 30 sites per year -- some on interstate routes and some on non-state roads in cities.

Railroads

Year(s): 1992

Source: Kansas Department of Transportation, Bureau of Rail Affairs
Kansas State Rail Plan

Variables: Traffic volume (Million Gross Vehicle Tons), Line type

KDOT maintains several sources of data on rail transportation. The Rail Plan includes data on the location, classification, and use of rail lines in the state. Base data for charts and summaries in the Rail Plan are provided. The Kansas Freight Density map shows patterns of rail traffic on a corridor basis.

Source of information: John Scheirman, Bureau Chief, KDOT Bureau of Rail Affairs (913) 296-4286

Contacts: Victor Eusebio, KDOT Rail Affairs (913) 296-7121

Steve Rindom, KDOT Rail Affairs (913) 296-4286

Pipelines

Year(s): 1993

Source: Kansas Geological Survey (Kansas state pipeline map)

Variables: Pipe Diameter, Material

State pipeline map by company, commodity, and pipeline capacity compiled by Kansas Geological Survey. Currently in digital format, but not database format. Worked with Kansas Geological Survey to convert to files readable by MapInfo.

Contact: Gina Ross, Kansas Geological Survey, University of Kansas, Moore Hall, 913-864-3965.

Waterways

Year(s): 1993

Source: Waterborne Commerce Statistics Center, U.S. Army Corps of Engineers, New Orleans

Variables: Total annual barge trips/miles/year along the portion of the Missouri River adjoining Kansas counties.

Total annual barge trips/mile/year transporting hazardous materials in Kansas.

Airports

Year(s): 1990

Source: The primary database used is available from a cd-rom titled 'Transportation Data Sampler -2' (publication BTS-CD-03).

The secondary database used is based on TIGER 92 data.

Variables: Total Operations

Fixed Facilities

KS312 Data Base

Year(s): 1992

Source: Kansas Department of Health and Environment

Variables: MaxRange, Fire, Pressure, Reactive, Immediate, Delayed, Chemical Weight

Contact at Health and Environment:

Teri Franklin (913) 296-5658

Original File Name on Diskette: KS312.ASC

313 Toxic Release Report

Year(s): 1992

Source: Kansas Department of Health and Environment

Variables: Chemical name, quantity spilled, fixed facility address

Kansas Department of Health & Environment (KDHE) maintains data on the ongoing release of toxic substances to the air (Toxic Release reporting), and on the storage, handling or processing of hazardous materials at specific sites (Tier 2 reporting) in the state. Carol Hastings of KDHE Office of Information Systems/Systems Development provided ASCII databases of 1992 Tier 2 facilities (312 reports) and 1992 Toxic Release Data (313 reports).

SARA Title III Spill and Response Report

Database used to derive spill rate for fixed facilities and verify spill rates for other modes.

Year(s): 1993

Source: Kansas Division of Emergency Preparedness

Assumptions: Out of all spills, 1,297 in 1993 database were located at fixed facilities.

Total fixed facilities = 6, 052

Variables: Incident Mode =FF

Contact at Emergency Preparedness:

Frank Moussa, Gabe Faimon, Steve Squires

Original File Name on Diskette:

# of Disks of original Data: 7

Future data availability: 1992, 1993 already available. 1994 data available in 1995.

VULNERABILITY ANALYSIS VALUES

Population Density

Year(s): **1992**

Source: Kansas Statistical Abstract, Institute of Public Policy and Business Research

Variables: Number of people, area of the county

Description: Population per square mile (population density) is given for all counties

Special Facilities

Kansas Nursing Homes

Years: 1994

Source: Kansas Department of Health and Environment

Variables: Number of beds

Specifics: Contact at Kansas Department Health and Environment

Dorothy M. Weir

Description: Long term care units in Kansas, both homes and units of hospitals.

Kansas Hospitals

Year(s): 1992 updated to 1994

Source: Kansas Department of Health and Environment

Parameters: Number of beds (patient census)

Contact: Terri O'Brate, Kansas Department of Health and Environment

(913) 296-5645

Public & Private Schools

Year(s): 1994

Source: Kansas Department of Education

Variables: Number of children

Contact: Ron Rohrer at (913)-296-3201

Stadiums

Year(s): 1994

Source: Pittsburg University, Kansas University, Baker University, K-State University, Emporia State University, Wichita State University, Wichita State University, Washburn University and Haskell University.

Variables: Type, Capacity

Prisons

Year(s): Correctional facilities : July 1994 - February 1995

County jails: 1993

Source: Office of the Secretary, Department of Corrections

Variables: Average daily population

Contact: Bill Miskell, Kansas Department of Corrections

(913) 296-3310

Land Use Values

Kansas Land Cover

Year(s): January 1991 to January 1994 (3-year time period)

Source: Kansas Applied Remote Sensing (KARS) Program

Variables: Residential, Commercial, Agriculture, Other

Contact: Stephen L. Egbert, University of Kansas, Nichols Hall, Lawrence

Format of original data: Quattro®

Environment Values

Year(s): January 1991 to January 1994 (3-year time period)

Source: Kansas Applied Remote Sensing (KARS) Program

Variables: Area of surface water

Contact: Stephen L. Egbert, University of Kansas, Nichols Hall, Lawrence

Format of original data: Quattro®

Water Treatment Plants

Year(s): 1994

Source: Bureau of Water, Kansas Department of Health and Environment

Variables: Surface water, ground wells, population served

Contact: Claudine Dunn, Public Water Supply Section, Department of Health and Environment (913) 296-0735.

The Technical Manual provided in Appendix 5 provides a complete list of data sources by variable in the application model.

Chapter 2 References

1. *Hazardous Materials Transportation Study Report*, Minnesota Emergency Response Commission, Department of Public Safety, June 1994.

2. *Users Guide to HazPlannER*, Abkowitz and Associates, Inc., 1994.

3. *The State-Wide Radioactive Materials Transportation Plan, Phase I and II*, Nevada Department of Transportation, December 1989.

CHAPTER 3

HAZARD ANALYSIS

3.1 Introduction

The term hazard analysis is used to describe the overall procedure for evaluating the hazards, probabilities, consequences and risks associated with the presence of hazardous materials within any given locality or jurisdiction. A hazardous analysis is a necessary step in comprehensive emergency planning for a community. The hazardous analysis is designed to consider all potential acute health hazards within the planning district and to identify which hazards are of high priority and should be addressed in the emergency response planning process. Comprehensive planning depends upon a clear understanding of what hazards exit and what risk they pose for the community. The hazardous analysis is a three- step decision making process to identify the potential hazards facing the community with respect to accidental releases of hazardous materials. *(1)* The three basic steps are:

1. *Hazards identification* - identification of the location, quantity, storage conditions and the specific hazards posed by the hazardous chemicals transported. manufactured, stored, processed and used in the community.
2. *Risk analysis* - evaluation of the likelihood of individual accident scenarios and the severity of the releases.
3. *Vulnerability analysis* - location of the geographical areas and the people, property, services and the natural areas that may be affected by a release.

3.2 Hazards Identification

Hazards identification is the process of collecting information on:

- types and quantities of hazardous materials in a community
- location of the facilities that use, produce or store hazardous materials
- transportation routes used for transporting hazardous materials
- potential hazards associated with spills or releases

This information can be used by emergency planners as well as by fire services, police departments and environmental protection departments - as they prepare for or respond to emergencies involving hazardous materials.

Hazards are situations that have the potential for causing injury to life and/ or damage to property and the environment. Chemicals may be potentially hazardous because of their toxicity or physical/ chemical properties such as flammability and reactivity. A system for developing a uniform approach to the measurement of relative threat from various hazardous chemicals is necessary. This can be achieved by ranking the hazardous materials or chemicals according to the threats they pose on human population as well as on environment.

3.3 Risk Analysis

Risk analysis provides a relative measure of the likelihood and severity of various possible hazardous events and enable the emergency plan to focus on the greatest potential risks. Risk may be defined as the probability of occurrence of an hazardous event. The evaluation of the probability of a future incident is based on the knowledge of the frequency with which that incident has occurred in the past. Prediction of the future, of course, is an inexact science, but probabalistic assessment methods can provide approximate indications of the number and nature of accidents expected on average in a given locale within specified period of time, and can hence provide valuable guideposts for decision making purposes. Records of the past events can therefore be put into practical use in risk analysis.

The computation of the annual accident probability associated with any specific activity involves using the frequency with which such accidents are known to occur in combination with a measure of 'exposure' of the community to the potentially hazardous activity. For most transportation modes, accident rates are presented in terms of number of accidents expected per mile of travel and exposures are expressed in terms of the number of trips made per year and the mileage of routes within the county. Multiplication of these values provides the expected number of accidents per year involving the activity being considered.

Risk analysis requires the use of specific local data; but in the absence of such specific data, average national accident rates determined from historical records and relevant exposure data are used. The ultimate goal, after all, is not exact estimation of accident probabilities, but their approximation at a level of accuracy sufficient for emergency planning purposes. Exact accident rates for the state of Kansas when available were used as inputs to the model. National accident rates were used as 'default' values when segment rates were not available. User interface routines allow for updated or location specific data when it is available.

The Risk Factors are calculated for six primary transportation activities associated with hazardous materials, each with a potential to cause hazards resulting in public emergencies. A brief summary of the types of information generally needed from these activities for conducting a risk analysis are as follows:

HIGHWAY TRANSPORTATION

- Length of routes by segments
- Specific hazardous cargos
- Number of trucks passing through the segments (Average Daily Truck Traffic)

RAILWAY TRANSPORTATION

- Routes and associated mileage through counties
- Classification of tracks
- Location and layout of railroad yards
- Specific hazardous cargos
- Number of cars passing the segments

PIPELINE TRANSPORTATION

- Mileage of pipeline routes
- Contents of pipelines
- Diameter of pipelines

WATERWAY TRANSPORTATION

- Mileage of routes
- Specific hazardous cargos
- Number of ships or barges passing though the routes

AIRWAY TRANSPORTATION

- Location of air terminals
- Number of flight operations
- Specific hazardous cargos

FIXED FACILITIES

- Location of facilities
- Number of spills
- Type of hazardous materials stored
- Quantity of hazardous material stored

3.4 Vulnerability Analysis

Vulnerability is the measure of the likelihood of injury, damage or loss due to exposure, insufficient procedures and response. Calculating a vulnerability factor requires identifying the areas in the community that may be susceptible to damage and the population that may be subject to injury or death, in the event of a hazardous material release. Populations usually considered include both residents and high density transient populations such as spectators in stadiums, sensitive populations in schools, prisons, hospitals and nursing homes that could be expected to be within the vulnerable zones. Vulnerability analysis also includes identifying and weighting essential support systems (e.g.,water treatment plants) and sensitive environments (e.g., drinking water supplies, food crops etc.) Consideration of property and environment are particularly important for chemical releases that pose hazard.

The major factors considered in this model in vulnerability analysis are:

- Population density
- Environment
- Land use value
- Water treatment plants
- Special facilities- Hospitals, Nursing homes, Schools, Prisons and Stadiums

3.5 Risk Index

Once risk and vulnerability factors were calculated, the relative Risk Index for each county could be calculated. Risk Index may be defined as the product of Risk Factor (RF) and Vulnerability Factor (VF). Risk Factor is the probability of occurrence of an hazardous event, where the probability term represents an hazardous material accident rate, in units of accidents per vehicle or accidents per facility as in a fixed facility; and the vulnerability represents the consequence term, measuring population potentially exposed to a hazardous materials accident.

The risk values calculated by the equations developed here, are considered a measure of relative risk rather than an absolute risk. The relative risk value for a single county doesn't provide specific guidance for local emergency management. The risk values are important only when compared to similarly derived risk values for other counties.

Chapter 3 References

1. *Technical Guidance for Hazard Analysis* (1987). USEPA, FEMA, USDOT.

CHAPTER 4

DEVELOPMENT OF THE MODEL

4.1 Introduction to the Risk Index Model

This chapter provides a process for evaluating the relative risks of all the counties of Kansas associated with the transportation as well as the storage of hazardous materials. The transportation and use of hazardous materials pose threats that are of concern to society, but are not fully understood in terms of their likelihood of occurrence or viewed in perspective with regard to their relation to other threats. The basic information, data and procedures necessary to evaluate and refine the individual hazardous material accident scenarios in terms of their annual probability or frequency of occurrence are described here.

A process was necessary with which to evaluate and refine the individual hazardous material accident scenarios in terms of their annual probability or frequency of occurrence. Two primary components were essential in establishing a Risk Index for all counties in Kansas: risk factor and vulnerability factor. The Risk Index is the product of these two components.

The Risk Index values calculated by the equations developed here are considered a measure of relative risk rather than an absolute risk. The relative risk value for a single county does not provide guidance for local decision. Rather, the risk values are important only when they are compared to similarly-derived risk values for other counties.

4.2 Risk Factor Equations

As explained in the previous chapter, the Risk Factor is calculated based on the probability theory. It depends on the probability of occurrence of an accident involving hazardous materials. The Risk Factor is calculated for carriers of hazardous materials on different modes, which include:

- Highways
- Railroads
- Pipelines
- Waterways
- Airports
- Fixed facilities

The general expression for Risk Factor is

$$RISK\ FACTOR = ar * sp * hc * gs \sum (n_i * L_i * m1_i * m2_i * 1 / sf_i)$$

where,

ar	=	Accident rate
sp	=	Spill probability
c	=	Hazardous material carriers (%)
n_i	=	Number of carriers
L_i	=	Length of route
$m1_i$	=	Adjustment factor for the level of risk of hazardous material (chemical ranking)
$m2_i$	=	Adjustment for the quantity of material (Adjustment factor for the weight)

sf_i = Safety Response Factor

gs = Percent of material spilled on ground (Ground / spill ratio)

Accident rates are presented in terms of number of accidents expected per year per mile of travel or per year per facility as in fixed facilities. Spill probability is the fraction of accidents that result in a spill or discharge and is expressed in percentage. Out of the total number of carriers, only a small percentage carries hazardous materials and this percentage is represented by the letter *hc*. The percentage of hazardous material that is going to be spilled on the ground, in the event of an accident is denoted by *gs*, which is the ground to spill ratio. The method for calculating ground-spill ratio for different modes is explained in Appendix 3.

The intensity of risk posed by a chemical depends on its level of hazard with respect to its toxicity, fire and explosive nature. It is important to measure the relative levels of threat of various hazardous materials because of the wide diversity in these materials with respect to toxicity, fire and explosive potential and their reactivity with other substances. There have been several attempts by various agencies to rank hazardous chemicals with respect to one or more of the above criteria. The National Fire Protection Agency (NFPA) developed a rating scheme, which is published in FEMA's Report RR-34/September 1990. The rating of a chemical in the NFPA scheme is based on its toxicity level, fire and explosive nature, mobility in atmosphere, domestic production and domestic shipments. The ranking is expressed as a product of the intensive hazard ratings (toxicity, fire and explosion) and the extensive quantity ratings (production and shipment). Since there is no sufficient data available for the production and shipment of the materials, this ranking system was not chosen in the model. The EPA Industrial Laboratory's ranking system considers the quantities of material released and the toxicity, but does not include measures for relative fire and explosive characteristics of the substance. Upon recommendation from the Project Advisory Committee, the ranking system developed by Richard J. Lewis's *SAX's Dangerous Properties of Industrial Materials (1)* is used in assigning the chemical ranking value in this model. The rating is based primarily on the toxic nature of the chemical, a characteristic determined by the Project Advisory Committee as most relevant to regional emergency response preparedness. A hazard rating is assigned to each material in the form of a number 0, 1, 2 or 3 that briefly identifies the level of hazard. Ratings are assigned on the basis of nil (0), low (1), medium (2) or high (3) toxic, fire, explosive or reactivity hazard, and the term $m1$ in the general expression of the equation represents this value. This ranking system should be of value to planners responsible for selecting those materials which represent the maximum danger to their local communities.

The quantity of hazardous material has a direct influence on the Risk Factor. This quantity depends upon the size and type of the carrier. It has been estimated that an average truck potentially can carry about 40,000 pounds of hazardous material. This value has been used as a base for expressing the quantity of material transported by other carriers, represented by $m2$. Since the quantity carried by a truck is the base line, the value of $m2$ for trucks is 1. The $m2$ value calculations for different modes are given in Appendix 4.

A parameter *sf* known as the Safety Response Parameter is introduced in the risk factor equation. This factor is based on the safety measures that could be available immediately at a location where there is an hazardous incident. The value attached to it depends upon the knowledge about the location of hazardous incident in advance, availability of equipment to counter the hazard and the presence of trained safety personnel at that location. Consequently, a rating of 1 to 100 is assigned for safety factor (*sf*). A rating of 1 indicates that there is no advanced knowledge of the location of an hazardous incident, potential quantity to be spilled and that there is an absence of on-site trained emergency personnel to immediately counter the hazard.

All carriers transporting hazardous materials have been assigned a default value of 1 in the existing application. Lack of sufficient information about the specific locations of potential spills and the non availability of emergency response personnel at the instance of an hazardous accident. Also, it is difficult to counter the hazard in an uncontrolled, open environment. A rating of 25 might still indicate a low response capability and no prior knowledge about the incident location. It also indicates that the emergency response is not in proximity. A rating of 50 is better in the sense that it is a reasonable situation representing average level of response availability and proximity from the hazard location. A value of 75 could be assigned when response is available within allowable proximity and better knowledge about the incident is available. More information about the chemicals and spills is also known.

A default rating of 100 has been assigned to fixed facilities because of safety measures incorporated in at least some of these facilities. In addition, the type of chemical, its reactivity and properties, quantity stored and the exact location are all known in advance in a fixed facility by local emergency response personnel. The whole operation is under controlled supervision. Trained safety personnel may be present and safety equipment is more likely to be installed at fixed facilities than would be possible in other modes. As specific local information becomes available for each fixed facility, the facility rating can be modified to represent the most appropriate level of safety readiness for each mode and each location.

4.2.1 Risk Factor for Highways

Growing consumer and industrial demand for products, that are potentially harmful materials, has resulted in greater movements of these commodities on the nation's highways. The highway transport of hazardous materials represents about 62 percent of the volume of hazardous material transported in the U.S. during the time 1992-1993. *(2)*

The risk factor for highways is given by

$$RFHW_j = HW_{spj} * HW_{hcj} * HW_{gs} \sum (HW_{ari} * ADTT_i * L_i * HW_{m1i} * Hw_{m2i} * 1 / HW_{sfi}) * 365$$

where,

$RFHW_j$	=	Risk factor for highways
HW_{arj}	=	Highway accident rate
	=	$2.74*10^{-6}$ / truck mile for US and State highways
	=	$1.23*10^{-6}$ / truck mile for Interstates
HW_{spj}	=	Highway spill probability, 20%
HW_{hcj}	=	Trucks carrying hazardous materials (%), 4
HW_{gs}	=	Ground to spill ratio (%), 3.5
$ADTT_i$	=	Average daily truck traffic
L_i	=	Length of segment, miles
HW_{m1i}	=	Ranking of chemical, 2
HW_{m2i}	=	Adjustment factor for the weight, 1
HW_{sfi}	=	Highway response safety factor, 1

Note: Numbers given after each variable represent the default values established for 1995.

The rate of accidents can be a function of road type (urban, rural), number of lanes, traffic density, average speeds, road conditions, weather conditions and geometry of the road. Differential accident rates were used for interstate highways, state highways and US highways in Kansas as default values. *(3)* With respect to the fraction of truck accidents that result in a spill or discharge, a value of 0.2 is adopted. *(4)* Whenever adequate local data are available for the determination of individual accident rates for divided or undivided roadways or for interstates and highways, their use is highly recommended because the resulting rates will more accurately reflect accident probabilities under local conditions. The program facilitates this update. The percentage of hazardous material that is going to be spilled on the ground is estimated by considering a 30-mile roadway segment with an average daily truck traffic of 400. The 1994 spill database of the state of Kansas was used to determine the average amount of material spilled on ground per incident. This database has a total of 120 incidences reported, resulting in spills totaling 168,950 pounds, approximately 1,400 pounds per incident.

The Average Daily Truck Traffic (ADTT) rate is attached to individual segments of the roadways and are summed to provide the total ADTT for that county. The lengths of the segments are also added to get the total length of the roadway in that county. Since commodity flow studies are limited or non-existent, data about the type of material carried are unknown. As the ranking or the level of risk involved directly depends upon the type of chemical, in all cases where there is an absence of information about the type of chemical carried, a medium level of risk is assumed. This assumption attaches a default value of 2 for the parameter $m1$ in the equation. The quantity of hazardous material carried by a truck is taken as the base value for estimating the weight of the material, and hence the value of $m2$ is equal to 1.

4.2.2 *Risk Factor for Railroads*

The risk factor for railroads is given by

$$RFRR_j = (RRM_{arj} * RRM_{spj} * RR_{rc} * RR_{gs}) \sum (G_i * L_{mi} * RR_{m1i} * RR_{m2i} * 1/ RR_{sfi}) +$$
$$(RRY_{arj} * RRY_{spj} * RR_{rc} * RR_{gs}) \sum (G_i * L_{yi}/L_{mi} * RR_{m1i} * RR_{m2i} * 1/RR_{sfi})$$

where,

$RFRR_j$	=	Risk factor for railroads
RRM_{arj}	=	Main line accident rate, 0.6 * 10^{-6} / car-mile
RRM_{spj}	=	Spill probability on main lines, 15%
RRY_{arj}	=	Yard accident rate, 3 * 10^{-6} / car-mile
RRY_{spj}	=	Spill probability in yards (%), 15
RR_{rc}	=	Cars carrying hazardous materials (%), 5.4
RR_{gs}	=	Ground to spill ratio (%), 3.5
G_i	=	Number of cars = Gross weight (mil.ton) / year / 67 ton per car
L_{mi}	=	Length of main line, miles
L_{yi}	=	Length of yard line, miles
RR_{m1i}	=	Ranking of chemical, 2
RR_{m2i}	=	Adjustment factor for weight, 1.35
RR_{sfi}	=	Railroad safety response factor, 1

Note: Numbers given after each variable definition represent the default values established for 1995.

Hazardous materials comprise 5.4 percent of rail tonnage, with an estimated one out of three trains carrying hazardous materials. National average accident rates are used as default values in the risk formula, whereas all other values are taken from data provided by the Bureau of

Rail Affairs of the Kansas Department of Transportation. *(5)* The national average suggests that an accident rate of $3 * 10^{-6}$ per train mile be used for main track. To convert this to a per car mile basis, it is assumed that 20 percent of the cars will be damaged in an accident. The overall rate therefore becomes $0.2*3*10^{-6}$ per train mile or $6 * 10$ per car mile. The accident rate for rail yards is obtained by taking $1.3*10^{-5}$ accidents per train mile and a 20 percent damage estimate to obtain about $3 * 10^{-6}$ car-mile for the track in yards. It is suggested that 15 percent of accidents be assumed as resulting in a spill for both main line and yard accidents. *(6)*

About 60 percent of the car is filled and the other 40 percent is empty. Therefore, on an average, weight of a box car is (0.6)(85) + 0.4(40) = 67 tons. This includes a loaded weight of 85 tons, tare weight of 40 tons and 40 percent of the box cars are empty. This results in an average weight of material carried by a box car to be (67-40) = 27 tons, which is equal to 54,000 pounds. This sets the value of *m2* to be (54,000/40,000) = 1.35. Neither the 1993 spill database nor the 1994 spill database has enough spills reported so as to estimate an average amount of spill. The six spills reported may not be the true representation, as it looks like they may be under-reported. Hence it was assumed that an average of 3.5 percent of the potential hazardous material involved in accidents would fall on ground in an accident, similar to highways.

4.2.3 Risk Factor for Pipelines

Pipelines in the United States primarily carry petroleum liquids, such as crude oil, gasoline and natural gas liquids, and energy gases which include natural gas and liquefied petroleum gas (LPG). To a smaller extent, pipelines also transport ethane, ethylene, anhydrous ammonia and many other chemicals. The main chemicals carried by pipelines in the state of Kansas include liquid ammonia, crude oil, LPG, helium and gasoline.

The risk factor for pipelines is given by

$$\begin{aligned} RFPL_j = {} & (PLU_{arj} * PLU_{spj} * PLU_{pc} * PL_{gs}) * \sum(L_{ju} * PL_{m1i} * PL_{m2i} * 1/PL_{sti}) + \\ & (PLL_{arj} * PLL_{spj} * PLL_{pc} * PL_{gs}) * \sum(L_{i<20} * PL_{m1i} * PL_{m2i} * 1/PL_{sti}) + \\ & (PLG_{arj} * PLG_{spj} * PLG_{pc} * PL_{gs}) * \sum (L_{j>20} * PL_{m1i} * PL_{m2i} * 1/PL_{sti}) \end{aligned}$$

where,

$RFPL_j$	=	Risk factor for pipelines
PLU_{arj}	=	Accident rate for pipe of unknown diameter, $1.5*10^{-3}$ /mile-yr
PLL_{arj}	=	Accident rate for pipe less than 20" diameter, $1.5*10^{-3}$ /mile-yr
PLG_{arj}	=	Accident rate for pipe equal to or greater than 20" diameter, $5*10^{-3}$ / mile-year
PL_{gs}	=	Ground to spill ratio (%), 0.04
L_{ju}	=	Length of pipeline of unknown diameter
$L_{j<20}$	=	Length of pipeline of less than 20" diameter
$L_{j>=20}$	=	Length of pipeline of 20" or higher diameter

PL_{m1i}	=	Ranking of chemical
PL_{m2i}	=	Adjustment factor for weight
PL_{sfi}	=	Pipeline safety response factor, 1
PLU_{spj}, PLL_{spj}, PLL_{spj}	=	Spill probabilities, 100%
PLU_{pc}, PLL_{pc}, PLG_{pc}	=	Pipes carrying hazardous materials, 100%

Note: Numbers given after each variable definition represent the default values established for 1995.

Accident rates for pipelines are generally given in terms of failure per unit length per year. An accident rate of $1.5 * 10^{-3}$ per mile-year is suggested for pipelines of unknown size and less than 20 inches in diameter. For pipelines with diameters greater than or equal to 20 inches, a rate of $5 * 10^{-4}$ per mile-year is proposed. *(7)*

The average diameter of pipelines that run in the state of Kansas is found to be 6 inches. A 30 mile line of 6 inch diameter pipe is considered to calculate the percent of material which would fall on ground in the event of an accident, as 6-inch diameter represents the average size of the pipelines in Kansas.

The quantity of material carried in pipelines in Kansas was not available in existing database. But, this can be estimated by calculating the volume of pipe per unit length and by knowing the unit weight of the chemical being carried. The product of these two gives the quantity carried and hence the weight adjustment factor *m2* can be determined. The ground-spill ratio calculation is shown in Appendix 3.

4.2.4 Risk Factor for Waterways

A large portion of the hazardous materials shipped annually in the United States is transported by barge or other marine vessel on coastal and inland waterways. In Kansas, the amount is limited due to the relatively small length of navigable inland waterways, about 94 miles on the Missouri river.

The risk factor for waterways is given by

$$RFWW_j = (WW_{arj} * WW_{spj} * WW_{wc} * WW_{gs}) \sum (n_i * L_i * WW_{m1i} * WW_{m2i} * 1/WW_{sfi})$$

where,

$RRWW_j$	=	Risk factor for waterways
WW_{spj}	=	Waterway spill probability (%), 15
WW_{arj}	=	Waterway accident rate, 15* 10^{-6} / barge-mile
WW_{wc}	=	Hazardous material carrying trips (%), 8.25
WW_{gs}	=	Ground to spill ratio (%), 3.5
n_j	=	Number of trips, 5679
L_j	=	Length of navigable water, miles
WW_{m1i}	=	Ranking of chemical, 2
WW_{m2i}	=	Adjustment factor for weight, 45
WW_{sfi}	=	Waterway safety response factor, 1

Note: Numbers given after each variable definition represent the default values established for 1995.

There are four Kansas counties through which barges travel on navigable waters. Individual shipments can be vastly larger than those carried by rail or truck. National accident rates and spill probabilities for barge traffic in the U.S. are provided in the *Handbook of Chemical Hazard Analysis Procedures. (8)* Barge traffic frequencies, the percent of barges carrying hazardous materials and the quantity transported are provided by the Navigation Data Center of the U.S. Corps of Engineers. *(9)* From this data, the weight of hazardous material cargo transported per trip per barge is found to be 1.8 million pounds, hence, the weight adjustment factor is 45. Since no data are available about the average amount of material spilled, a ground-spill ratio of 3.5 percent was assumed.

4.2.5 Risk Factor for Airports

The risk factor for airports is given by

$$RFAW_j = (AW_{arj} * AW_{sp} * AW_{ac} * AW_{gs}) \sum (TOPS_j * AW_{m1j} * AW_{m2j} * 1/AP_{s1j})$$

where,

$RFAW_j$	=	Risk factor for airports
AW_{arj}	=	Accident rate, $13 * 10^{-6}$ / operation
AW_{spj}	=	Spill probability, 100%
AW_{ac}	=	Airplanes carrying hazardous materials (%), 100
AW_{gs}	=	Ground to spill ratio (%), 3.5
$TOPS_j$	=	Total number of operations
AW_{m1j}	=	Ranking of chemical, 3

AW_{m2j} = Adjustment factor for weight, 0.015

AP_{sfi} = Airport safety response factor, 1

Note: Numbers given after each variable definition represent the default values established for 1995.

The transportation of hazardous materials in air in the state of Kansas is limited to small packages, but this category of accidents applies to crop dusters applying pesticides. It has been observed that there are relatively few hazardous materials incidents each year involving this mode of transportation. The accidents tend to concentrate in the vicinity of airports. In terms of emergency response planning, there is little that can be done to accurately determine the potential risk involved in this type of accident because of the extremely incomplete data available on commodity flows. The risk factor equation is applicable to light aircrafts which are assumed to carry about 600 pounds of jet engine oil as fuel. *(10)* No information is available about the quantity of other hazardous materials carried. However, the model has the provision of inputting the chemical and its quantity whenever such data are available. An accident rate of $13 * 10^{-6}$ per operation of an aircraft is used. *(11)* The number of aircraft operations in Kansas was provided by the Kansas Division of Aviation. *(12)*

4.2.6 Risk Factor for Fixed Facilities

The risk factor for fixed facilities is given by

$$FFRF_j = FF_{arj} * FF_{spj} * FF_{hcj} * \sum(FF_{gsi} * FF_{m2i} * FF_{m1i}) * 1/FF_{sfi}$$

where,

$FFRF_j$	=	Risk factor for fixed facilities
FF_{arj}	=	Fixed facility accident rate, 0.085/chemical
FF_{spj}	=	Fixed facility spill probability, 100%
FF_{hcj}	=	Facilities storing hazardous material (%), 100
FF_{gsi}	=	Ground to spill ratio (%)
	=	(0.75* amount stored / amount stored) for facilities storing less than 99,999 lbs
	=	5,000 lbs / amount stored, for facilities storing 99,999 lbs or higher
FF_{m1}	=	Ranking of the chemical, 0-3
FF_{m2}	=	Adjustment factor for weight, Weight stored/40,000
FF_{sfi}	=	Fixed facility safety response factor, 100

Note: Numbers given after each variable definition represent the default values established for 1995.

The 1992 fixed facility data base for the state of Kansas does not contain the exact amount of material that is stored in the facility. Instead, it gives the range containing the amount stored. There are eight ranges starting from 0 - 99 pounds to 99 - 999 pounds, 999 - 9999 pounds and so on. To make a conservative estimate of risk, the maximum value in each of these ranges is selected to represent the quantity stored in the corresponding facilities.

To establish a relationship between the quantity of material stored in the facilities and the amount of materials spilled from these facilities, the 1994 spill data base (SARA Title III Spill and Response Report, 1994, provided by Kansas Division of Emergency Management) and the 1992 database of fixed facilities reporting under Section 312 of the Title III Emergency Planning and Community Right-to-Know Act of 1986 requiring facilities to submit an emergency and hazardous chemical inventory form, were studied. The fixed facility electronic database was provided by the Kansas Department of Health and Environment which maintains the 312 inventory. It is found that virtually no data exists to match or to compare the two databases. From the spill database, approximately 70 records matched with the fixed facility database. Besides, the spill database does not contain any report indicating a spill in a facility which stores less than 9,999 pounds. that matched with the fixed facility database. Under these limitations, best possible judgment and assumptions are applied in developing default values for the fixed facility risk factor equation.

The 1994 spill database has about 1,456 incidences of spill reported from fixed facilities. The average quantity of spill per incident from this database is found to be approximately 5,094 pounds. According to 1992 fixed facilities database, more than 70 percent of the facilities store 99,999 pounds or higher amount of chemicals. Hence, it was assumed that for facilities storing 99,999 pounds or higher amount of chemicals, the quantity of material spilled on ground is 5,094 pounds. For smaller facilities, 75 percent of the amount stored was assumed to result in spills. This assumption was based on the fact that as the facility size decreases, even though the quantity spilled must be less, it is likely that a greater percentage would Larger facilities have better safety measures which would make them more safer.

There are 17,168 chemicals stored in facilities according to 1992 fixed facility database. Out of these facilities, 1,456 incidences of spills were reported in the spill database. This would result in an accident rate of 1456/17,168 = 0.085 per chemical stored per year.

4.3 Vulnerability Factor Equations

Vulnerability analysis identifies areas in the community that may be affected or exposed, individuals in the community who may be subject to injury or death from certain specific hazardous materials, and facilities, property or environment that may be susceptible to damage should a hazardous materials release occur. The vulnerability is expressed in terms of a Vulnerability Factor (VF).

All the vulnerability factors are not equally vulnerable in the event of a hazardous materials release. Some of them are more prone to danger or risk compared to others, should a release happen. Consequently, each of them are weighed differently depending upon their susceptibilities with respect to the same hazardous incident. Since human life is given the highest priority, wherever there is a direct involvement of people, maximum weightage is given. Hence, population density and special facilities are each given 30 percent of the total weightage. Water treatment plants, which serve the community and are essential to the survival of the population, are recognized as the next vulnerable facilities and are assigned a weightage of 20 percent. Environment, which includes the surface water in each county, and the land use value are each given a weightage of 10 percent.

The total vulnerability factor (VF) for a county is the summation of all the above mentioned vulnerability factors calculated individually for these entities. The Vulnerability Factor thus for a county is given by

$$VF = VFPD + VFLU + VFSF + VFWP$$

where,

VF	=	Vulnerability factor
VFPD	=	Vulnerability factor for population density
VFLU	=	Vulnerability factor for land use
VFSF	=	Vulnerability factor for special facilities
VFWP	=	Vulnerability factor for water treatment plants

4.3.1 Population Density

Population density is the number of people per square mile in a county. The Vulnerability Factor for population density measures the risk to human life by the transportation of hazardous materials. The county which has the maximum population density in the stat of Kansas is the most vulnerable county.

The Vulnerability Factor for population density (VFPD) is given by

VFPD = (Population density in the county / Maximum population density in any county)*0.30

4.3.2 Land Use Value

The land can be classified into following different types : Residential, Commercial, Agricultural and Other. The category *other* includes open lands, forests, prairies and other generally unpopulated, undeveloped areas. Each of the land use types can be assigned a value depending on the priority given to the type of land. Highest priority is given to residential land, which would face the most severe consequence in the event of a release and assigned the maximum value of 4. Values for the other land use categories are: Residential - 4, Commercial - 3, Agricultural - 2 and Other - 1.

The general equation to calculate land use value for each county is given as:

Land Use Value = [Other * 1 + Agricultural * 2 + Commercial * 3 + Residential * 4] * (area of county)

Now, the Vulnerability Factor for land use value (VFLU) is given by,

VFLU = (Land use value for the county / Maximum land use value for any county) * 0.10

4.3.3 Environment

The area of surface water present in the county is considered under environment since water can get contaminated in the event of a hazardous materials release. The level of concern depends upon the area of waterway. Hence, the area of surface water present in each county is determined.

The Vulnerability Factor for the environment (VFEN) is given by,

VFEN = (Area of waterway in the county / Maximum area of waterway in any county) * 0.10

4.3.4 Special Facilities

Special facilities are unique facilities, in the sense that they are highly vulnerable to any incident involving hazardous materials. These facilities have limitations in their own way when it comes to evacuating people from them in the event of a release. Five distinguished facilities are identified under the category of special facilities. Depending upon the type of occupants and the arrangements available to evacuate these occupants during an emergency, each of these facilities are weighed again, so that the overall contribution from them is 30 percent towards Vulnerability Factor. The five facilities considered are : Hospitals, Nursing homes, Schools, Prisons and stadiums.

The Vulnerability Factor for each of them are given by the following expressions

Hospitals

VFHO = (Number of patients in the county / Max. number of patients in any county) * 0.08

Nursing homes

VFNH = (Number of beds in the county / Max. number of beds in any county) * 0.08

Schools

VFSC = (Number of students in the county / Max. number of students in any county) * 0.07

Prisons

VFSC = (Number of prisoners in the county / Max. number of prisoners in any county) * 0.05

Stadiums

VFST = (Number of spectators in the county / Max. number of spectators in any county) * 0.02

4.3.5 Water treatment plants

Water treatment plants are the means of serving drinking water to the community. Any adverse impact on these plants is directly reflected on the population they serve. It is necessary to measure the Vulnerability Factor for water treatment plants, which would determine its impact on people. The Vulnerability Factor (VFWP) is given by

VFWP = (Number of people served in the county / Max. number of people served in any county) * 0.20

Chapter 4 References

1. Lewis R.J., Sr. (1994) *Sax's Dangerous Properties of Industrial Materials.* New York: Van Nostrand Reinhold. CD-ROM.

2. *Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials* (1994, September). FHWA-SA-94-083, USDOT, Federal Highway Administration.

3. Paul W.H. and Radnor, P.J. (1979) *Highway Engineering*. New York: John Wiley and Sons, Inc. pp 73.

4. *Handbook of Chemical Hazard Analysis Procedures* (undated). FEMA, USDOT and USEPA.

5. Eusebio, V.E. and Rindom, S.J. (undated) *Rail Movements of Hazardous Materials in Kansas Bureau of Rail Affairs*, Kansas Department of Transportation, Topeka, Kansas.

6. *Handbook of Chemical Hazard Analysis Procedures* (undated). FEMA, USDOT and USEPA.

7. *Handbook of Chemical Hazard Analysis Procedures* (undated). FEMA, USDOT and USEPA.

8. *Handbook of Chemical Hazard Analysis Procedures* (undated). FEMA, USDOT and USEPA.

9. *Barge Trips and Tonnage on Missouri River, Mile 367-490* (1994). Navigation Data center, US Army Corps of Engineers.

10. Roskam, Jan (1989. *Airplane Design - Part 1: Preliminary Sizing of Airplanes*. Lawrence: University of Kansas.

11. Ashford N., Stanton H.P.M. and Moore A.C. (1984) *Airport Operations.* John Wiley and Sons.

12. *Kansas Aviation Systems Plan* (1992, January). Kansas Department of Transportation, Division of Aviation, Topeka, Kansas.

CHAPTER 5

GIS APPLICATION IN RISK ANALYSIS

5.1 Geographic Information System Platform

MapInfo for Windows™ was selected as the Geographic Information System (GIS) platform for this project. It was selected for several reasons. First, it is a Windows™-based product that supports DDE and DLL functions. While the DDE functionality was not used in this application, the DLL functionality was utilized to develop an easy-to-use user interface. The user-interface screens were written in Visual Basic™.

MapInfo™ has a very powerful development environment, called MapBasic™. All GIS functions and numerical calculations for risk and vulnerability factor calculations were conducted in MapBasic™. While MapBasic™ is generally recognized as being rather slow, it did not hinder the performance of this application. If it had, the project team could have developed a DLL using Visual C++™, or other language, to conduct the numerical calculations. Finally, there is a wealth of data available in the MapInfo™ format. When available, the project team took advantage of this data availability.[1]

[1]All references to MapInfo through the remainder of this chapter have omitted the trademark designation. MapInfo is a trademark product of MapInfo Corporation.

5.2 Development of Risk Factor Databases

The highway table was divided into three separate tables: Interstate, U.S. Federal and State. The source of all highway data was MapInfo's StreetInfo tables. These tables are based on the TIGER92 files. Searches were conducted for each county to find all streets whose names started with "I " or "I-" for interstates, "US HWY" for US Federal highways, and "ST HWY" for State highways. A small MapBasic program was written to automate this process. While somewhat surprising, the results of these searches provided a relatively complete set of highway maps. In many urban areas, streets starting with an "I" were also picked up but they were easily removed from the Interstate Table using the MapInfo editing tools. There were some problems in the highway maps due to errors in the street names. Those were remedied on a case-by-case basis and were not a major detriment to developing a complete set of highway maps for the state.

In each highway table, the map segments were merged so ADT and ADTT attribute values could be assigned to each segment. This merging of segments was done by hand and was rather labor intensive. In the future, a MapBasic application should be developed to expedite the procedure using a network generation module. Several criteria were used to merge these highway segments. A segment always stopped when it crossed a county boundary. Segments were also stopped at the intersection of two or more highways.

ADT and ADTT data was found from traffic volume maps provided by the Kansas Department of Transportation. *(1)* When a highway had two or more designations, the traffic volume was assigned to the table with the highest hierarchy designation. The highway hierarchy used was Interstate, US Federal and State Highways.

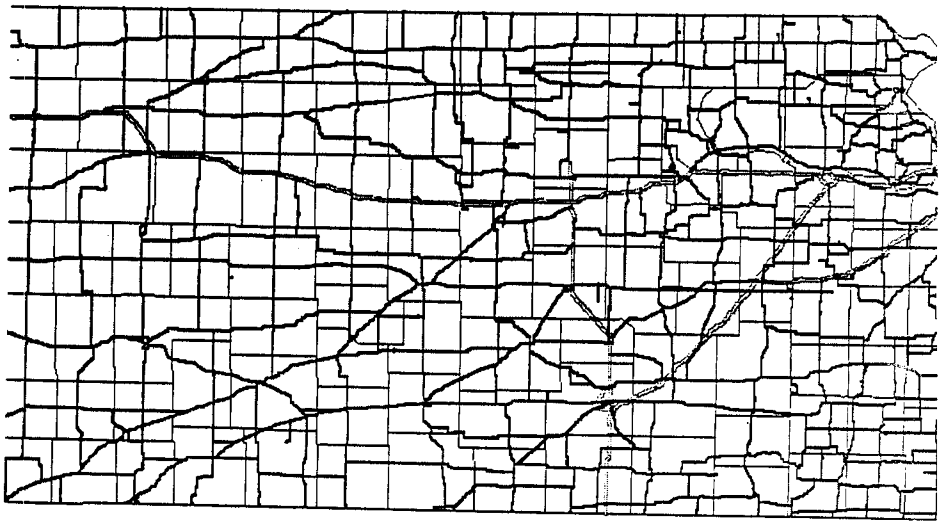


Figure 5-1 Interstate, US Federal and State Highway Map

Accident rates were also assigned to each segment. For the first pass, accident rates were assigned to each map segment based on highway type. In the future, the user could assign different accident rates to each highway segment. This would be very important if the user considered higher accident rates in construction zones. A map of Kansas highways is shown in Figure 5-1.

Railroads

The original source of the railroad files was the TIGER92 data. However, these files were modified in two different ways. Railroad companies abandoned significant track mileage in Kansas since the TIGER files were created. All abandoned mileage was eliminated from the Railroad Table. Again, the number of railroad segments were reduced by merging adjacent segments. Segments were broken at county boundaries and at all intersections of yard or main lines. An attribute, Line_Type, with the value of (M)ain Line or (Y)ard Line, was added to the railroad database. Finally, tonnage was assigned to each main line segment based on a map provided by the Bureau of Rail Affairs in the Kansas Department of Transportation. *(2)* A map of the railroad system in Kansas is shown in Figure 5-2.

Pipelines

The development of the pipeline map was different for several reasons. First, no pipeline data is found in the TIGER files. The only source of pipeline data, in electronic form, was found at the Kansas Geological Survey on a internally developed GIS package. *(3)* Unfortunately, it did not have a direct export capability. It could give x, y coordinates (latitude and longitude) of all object shape points. The developers of this map provided an ASCII file with latitude & longitude coordinates for each shape point. When a line started or ended, the coordinates (-1, -1) were inserted in the file.

The project team wrote a small MapBasic application to read this ASCII file and automatically generate the pipeline table. The coordinate data was for a pipeline corridor and

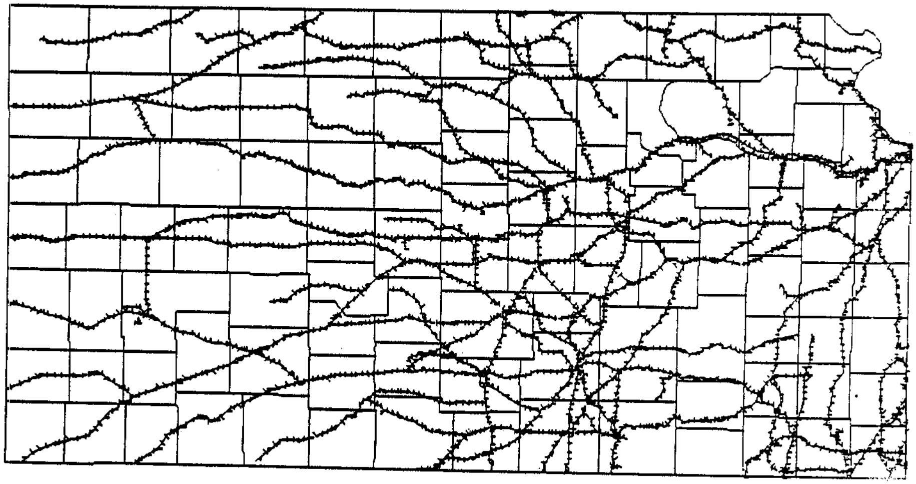


Figure 5-2 Kansas Railroad Map

not individual pipelines. As many as five pipelines were found in a corridor. Each pipeline corridor was broken at county boundaries.

Since no attribute data followed the pipeline coordinate file, pipeline diameter(s) and materials carried were entered by hand. When multiple pipelines occurred, the pipe diameter was inserted into a table field for pipe diameters. When no pipeline diameters were provided, it was assumed to be unknown. For each pipeline, the size parameter, m2, was calculated using the formula previously stated. For pipelines with unknown diameters, a 3.5 inch diameter pipeline was assumed.

From the original data source, materials carried in each corridor were obtained and assigned to a field. Each material was assigned a chemical ranking, m1 value. A map of the pipeline map is shown in Figure 5-3.

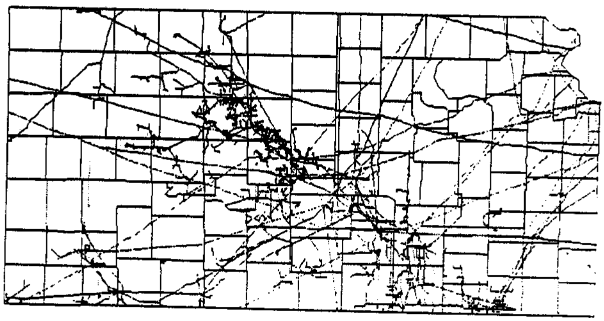


Figure 5-3 Pipeline Corridors

Waterways

Only four counties are adjacent to navigable waterways in Kansas. Therefore, all waterway attribute data was stored in a table of counties in tabular form.

Airports

All airports in Kansas were located in a table by digitizing the airports from a TIGER92 map. This original map showed airport runways, but a point symbol is more appropriate for this application. Besides the usual information such as Airport Name, etc., an attribute field containing the total number of annual operations was included. A document from Kansas Department of Transportation *(4)* gave the annual total operations for the larger airports. For the smaller airports, 1000 annual total number of operations was assumed.

Fixed Facilities

Fixed facilities imposed a unique set of GIS issues. The project team received a database of approximately 6750 fixed facilities from the state which store hazardous materials. *(5)* Unfortunately, in the development of this database, there was no consideration in geocoding the fixed facility database. The database contained the following location references: Address, Post Office Boxes, Public Land Surveys, County Name, and a distance and direction from a town. Since our only firm requirement was to locate the fixed facilities in the correct county, our requirements for locating these facilities were rather loose. However, the project team wanted to geocode the database as accurately as possible.

A MapBasic Application was written to call up street maps for each of the 105 counties. All fixed facilities were geocoded using the street name and address range with the automatic geocode option. For those fixed facilities that could not be geocoded exactly, they were geocoded to the street names and address ranges using the interactive mode found in MapInfo. Finally, the remaining fixed facilities were geocoded to the centroid of the 5 digit ZIP Code or the county.

Approximately one third of the fixed facilities were automatically geocoded to the exact street name and address range. Another one third were successfully geocoded in the interactive mode. The remainder of the facilities were geocoded to ZIP Code centroid or county centroid.

The fixed facility database contained the name of the hazardous material, an amount of chemical stored by eight different size categories and a SIC code for the chemical. This database was attached to a database of chemical ranking (0 - 3 scale) through the SIC code field. This chemical ranking was used as the $m1$ parameter.

This concludes the discussion of the Risk Factor components. Each map and attribute data was stored in the system. The application (KRISP) was developed to do the actual numerical calculations.

5.3 Development of Vulnerability Factor Databases

While Vulnerability Factors are an important component for a Risk Factor Analysis, they were not as difficult to import into a GIS application. As far as the GIS map was concerned, vulnerability factor data were attached to a county map unless noted. This is far simpler than most maps developed for the Risk Factor analysis.

Population Density

The Vulnerability Factor for population density is found by a table of population densities based on the 1990 Census Data.

Land Use

A database *(6)* was found that divided land use in a county into four components: residential, commercial, agricultural, and other. A land use value for each county was calculated by giving the four land area components weight factors of 4, 3, 2 and 1, respectively.

Environment

The water area in each county was the significant factor in this component. The water surface area for each county was found in a database and was used in this study. *(7)*

Water Treatment Plants

A database of water treatment plants was found. *(8)* It was geocoded using 5 digit ZIP Code Centroids. As part of the database, the number of people served was a field included in the database. Except for a few exceptions, it was assumed that all people served lived in the county of the ZIP Code.

Special Facilities

The Special Facilities contain all those items where people are congregated in large concentrations or where they are not able to rapidly move because of health, age or other factors. These components are: Hospitals *(9)*, Nursing Homes *(10)*, Public and Private Schools *(11)*, Prisons (Federal, State and Local) *(12)* and Stadiums. For each component, the locations were geocoded based on ZIP Code centroid. Calculation of the Vulnerability Factor component was similar in all cases. All counties of the appropriate table were searched to find the county with the most persons. Then, the ratio of the number of affected persons in each county to the maximum number of persons in the state was multiplied by a constant, or maximum valued for that component.

Once the Risk Factor and Vulnerability Factor formulas were developed, the remainder of the project involved developing the user interface and calculating each component. Finally, an easy to use user interface was developed to display the results of the analysis. The remainder of the paper will be spent discussing a Risk Index application.

5.4 GIS Application Development

As previously stated, all data was collected and incorporated into MapInfo for Windows tables. A separate table, KSCONTY was created to store the results of the latest numerical calculations. This approach was very beneficial when displaying and exporting the results. One of the other requirements of the application was that the software should export some of the parameters collected in the process. While we could export entire MapInfo tables for

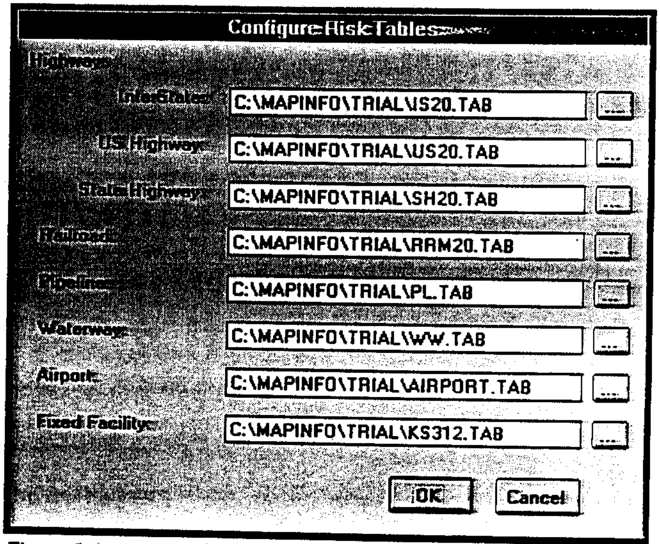


Figure 5-4 Typical Visual Basic Configuration Screen

each county, that was not the intent of the project. Therefore, aggregate data was stored for each component of the Risk and Vulnerability Factors.

The entire application was developed in MapBasic except for three user interface screens. These screens were developed in Visual Basic. This way the authors could take advantage of the robust user interface tools found in Visual Basic. The two applications were attached to one another using the Windows DLL function.

The application, Kansas Risk Index Software Package (KRISP), has the following modules: Configure Tables, Update, Display, Export, and Exit.

The Configure Tables module allows the user to select all tables associated with calculating the risk and vulnerability factors. When specific parameters are updated, the user can easily select the appropriate table. The Risk Factor Configure Menu is shown in Figure 5-4. As previously stated, this screen was written in Visual Basic.

The Update Module was developed to calculate, or update, Risk and/or Vulnerability Factors for each county. This screen was developed in Visual Basic and is shown in Figure 5-5. It permits the user to select one, many or all components for either Risk Factor or Vulnerability Factor. Once the user makes their selection, the software will calculate the appropriate component. This approach was a significant time saver when only data from one component was updated. Each time the module was used, the Risk Index for each county was automatically updated. These updated components were automatically stored in a MapInfo Table.

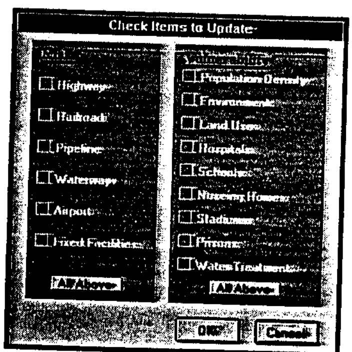


Figure 5-5 Update Module for Risk and Vulnerability Factor Calculations

While MapInfo has tools to develop thematic maps, KRISP has some tools in the Display module to make the user interface easier. For example, a screen similar to the one used in the Update module is presented so users may select the display of Risk Factors, Vulnerability Factors or Risk Index. For each option, the user may select the sum of one, many or all components. This works very nicely when one is trying to understand what the data is saying.

After selecting the data desired for display, the user may select to display the data with Range or Pie Chart option. If the Range Option is selected, the user may select the number of ranges desired. Finally, the user may select whether the Equal Count or Equal Range option is desired when displaying the ranges.

This approach has been found to be user friendly. Samples of output using both display options are found in Figures 5-6 and 5-7.

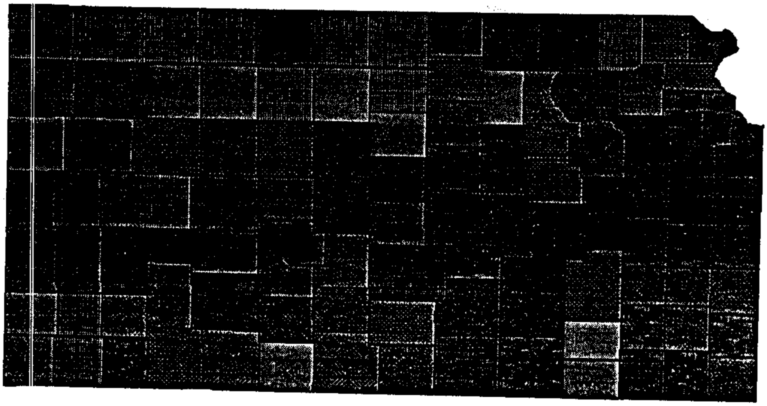


Figure 5-6 Equal Count for Total Risk Factors with 10 Ranges

The final option provided in KRISP is the Output module. The purpose of this module is to allow the user to down load, into a database, summary information for one or more counties. The screen developed for this module is shown in Figure 8. Again, this screen was developed in Visual Basic.

This screen supports many different features. The user may select one or both sets of data for each county. The first set of data, Risk/Vul, will provide the user the values of Risk and Vulnerability Factors for each component. The other set of data, Data Summary, provides the user with summaries of the raw data used to calculate Risk and Vulnerability Factors. The user has the option of putting the summary data into one database or into a separate database for each county selected.

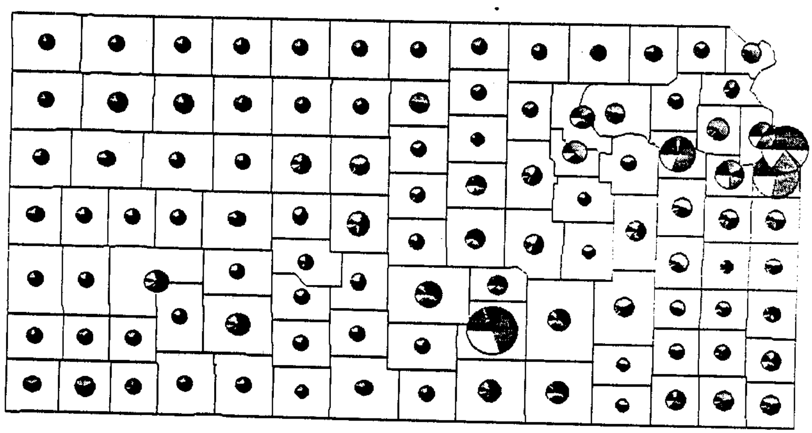


Figure 5-7 Total Vulnerability Factors using Pie Chart Display Option

Selection of the counties for data output is accomplished with the selection tool found in the middle of the screen. The user may scroll through the list of counties provided in the left column and select the desired ones. All counties selected are then displayed in the right column. If a county is selected by mistake, it can be deselected by clicking the deselected county in the right column.

5.5 Advantages of GIS Approach in Development of Model

The advantages of conducting this project in a GIS environment can not be overstated. While there was a price for integrating data from many different sources, the advantages far outweighed the disadvantages. One of the first advantages noted was in the development of the risk and vulnerability formulas. As the system was developed, the results were immediately displayed in a graphical form. When developing the components of risk or vulnerability factors, the use of the pie chart output option was particularly useful in determining the relative values of individual components.

Another advantage became apparent when existing data was updated. New tables could be created. With the Configuration Module, these tables could be easily incorporated into the KRISP database. With the Update Module developed, the component(s) with the new data could be calculated and displayed. This has proved to be a significant feature.

Another advantage is in the interpretation and use of the Risk Index values. Since one of the objectives of this project was to develop a tool to evaluate potential sites of regional hazardous materials response teams, the graphical display of the Risk Index is a valuable tool. Areas of high risk can be found and the sites selected appropriately.

5.6 Summary and Conclusions

A summary of a risk and vulnerability analysis for hazardous materials was presented. However, the thrust of the paper is a discussion of the integration of data found from various sources into a GIS environment. Much of the regional data were found from TIGER92 sources, in-house developed GIS systems, non graphical databases, ASCII formats and others. With the aid of some MapBasic Applications, import capability of MapInfo and hand insertion of attribute data, all data sources were brought into a common environment, MapInfo.

Once the common environment was accomplished, a MapBasic application called KRISP was developed. This application calculated Risk and Vulnerability Factors for each county in Kansas using the objects and attribute data of the appropriate table. The KRISP application was divided into several modules. This included the Update module to calculate the Risk and Vulnerability Factors, the Display module to assist the user in developing thematic maps using equal count, equal range, ranges or pie charts. In addition, an Output module to provide users in one or more databases summary data of the raw data or risk analysis data, or both.

Overall, the use of GIS in this application proved to be very beneficial. While other tools could be used, they would not be as clean as the approach selected. This is especially true as the raw data is updated. Since so much of the data is now correctly geocoded, the updating of the information will be relatively easy. The use of GIS also allows the user to display the results of the analysis. We found this very beneficial to find errors in the raw data and to evaluate alternatives in the development of the Risk and Vulnerability Factor equations.

The power of GIS is not limited to the immediate application. It has the ability to use existing data for other applications. For example, to determine which highways carry high volumes of total traffic or truck traffic, a map showing this data is readily available. If inspectors want to verify locations of fixed facilities, maps could be provided to the inspectors showing these locations. Of course, updating this data must be a continuing process for the data to provide a useful tool.

One of the other points that became apparent during the project is the need for consistency in the data collection process. For example, in the collection of the fixed facility database, the number of location reference systems was significant. Also, within one system, the data was entered in a variety of formats. For nongraphical databases, this approach may be acceptable. When tying this database to a GIS table, it becomes a major hurdle. For those who are collecting data which may eventually be tied to a GIS package, it will make this task much easier if attention is given to data format and consistency.

Chapter 5 References

1. *1992 Traffic Count Map* (1992). Bureau of Transportation Planning, Kansas Department of Transportation, Topeka, Kansas.

2. *Kansas State Rail Plan* (1992). Bureau of Rail Affiars, Kansas Department of Transportation, Topeka, Kansas.

3. *Kansas Pipeline Map* (1993). Kansas Geological Survey. University of Kansas, Lawrence.

4. *Kansas Aviation Systems Plan, Phase 4 - Appendix.* (1992). Kansas Division of Aviation, Department of Transportation, Topeka, Kansas.

5. Kansas 312 Fixed Facility Database (1993). Kansas Department of Health and Environment.

6. Kansas Land Use Database (1994). Kansas Applied Remote Sensing (KARS) Program. University of Kansas, Lawrence.

7. Kansas Land Use Database (1994). Kansas Applied Remote Sensing (KARS) Program. University of Kansas, Lawrence.

8. *Public Water Supply System Database* (1994). Bureau of Water, Kansas Department of Health and Environment, Topeka, Kansas.

9. *Nursing Homes and Hospital Databases for Kansas* (1994). Kansas Department of Health and Environment, Topeka, Kansas.

10. *Nursing Homes and Hospital Databases for Kansas* (1994). Kansas Department of Health and Environment, Topeka, Kansas.

11. *Public and Private School Databases* (1994). Kansas Department of Education. Topeka, Kansas.

12. *Prison Database* (1994). Office of the Secretary, Kansas Department of Corrections, Topeka, Kansas.

CHAPTER 6

RESULTS AND DISCUSSION

6.1 Introduction

As discussed in the previous chapter, the microcomputer-based model KRISP (Kansas Risk Index Software Package) was developed to assess a relative risk index for hazardous material transportation among Kansas counties. Application of Geographical Information System (GIS) technology to the model has offered a graphical interface to easily communicate risk and vulnerability among areas of the state. The relative values of risk and vulnerability are presented either in the form of thematic maps or as pie-charts.

This chapter presents the results of the developed model, calculated within KRISP. These results include both Risk Factor (RF) and Vulnerability Factor (VF) calculations for each mode in each county. The calculated Risk Index (RI) which is a product of RF and VF is also presented. A sensitivity analysis of individual components of the model was conducted and the results of that analysis are presented in a subsequent section. The purpose of the sensitivity analysis is to help the reader understand the impacts of a variety of assumptions made within the model on the results of the risk and vulnerability analysis.

6.2 Risk Factor Results

Comparing the overall risk factor values among all the transportation modes that carry hazardous materials, it has been found that the risk index was highest for fixed facilities of the modes considered. This high index is due to the very large quantities of materials stored and amounts spilled within these facilities. Risk associated with highways is the next highest, followed by railroads, waterways and airways. Pipelines have the lowest risk index based on amounts spilled, apparently due at least in part to the safety measures incorporated like flow restricting devices and the periodic inspection of the lines.

The mean risk factor value for fixed facilities is about 1.68 times higher than that of highways, ranging from .15 (Elk County) to 35 (Sedgwick County). The Highway Risk Factor ranges from .43 (Stanton County) to a value of approximately 10 (Johnson County). The mean risk factor value for highways is about 1.65 times higher than that of the railroads, and about 44 times higher than airports and pipelines. The value of total risk factor (RFTOTAL) from all modes of transportation and storage units varies from less than one (Elk County) to a maximum value of approximately 62 (Wyandotte County). A list of risk factors values by modes for all Kansas counties and the mean for each mode are provided in Table 6-1. The risk factor values displayed on a map generated by KRISP are illustrated in Figure 6-1 and Figure 6-2.

Atchison, Doniphan, Leavenworth and Wyandotte are the only four counties in the state through which hazardous materials are transported by barges. Consequently, the reader will note that the risk factor value for waterways (RFWW) for these counties reflects this exposure to risk; the remaining counties have a RFWW value of 0.

Table 6-1
Risk Factor by Mode for Kansas Counties

Kansas County (KSCNTY)	Highway Risk Factor (RFHW)	Pipeline Risk Factor (RFPL)	Railroad Risk Factor (RFRR)	Waterway Risk Factor (RFWW)	Airport Risk Factor (RFAP)	Fixed Facility (RFFF)	Total Risk Factor (RFTOTAL)
KSALLE	1.66	0.21	1.02	0	0.05	1.07	4.00
KSANDE	1.66	0.08	2.82	0	0.03	0.32	4.90
KSATCH	0.84	0.07	0.87	0.58	0.03	3.05	5.45
KSBARB	1.10	0.09	0.94	0	0.02	6.49	8.64
KSBART	2.65	0.05	0.81	0	0.11	16.96	20.58
KSBOUR	1.92	0.01	1.54	0	0.05	1.06	4.59
KSBROW	1.77	0.03	0.46	0	0.01	2.81	5.08
KSBUTL	6.18	0.28	3.84	0	0.10	11.26	21.65
KSCHAS	5.48	0.04	4.41	0	0.00	0.16	10.10
KSCHAU	0.76	0.07	0.00	0	0.01	0.40	1.24
KSCHER	2.86	0.03	0.85	0	0.01	2.16	5.91
KSCHEY	1.23	0.00	0.01	0	0.02	0.98	2.24
KSCLAR	1.63	0.10	0.09	0	0.02	2.00	3.83
KSCLAY	0.74	0.05	0.05	0	0.00	1.08	1.32
KSCLOU	2.06	0.07	0.19	0	0.04	1.75	4.11
KSCOFF	1.64	0.05	1.15	0	0.01	1.35	4.20
KSCOMA	0.47	0.05	0.00	0	0.01	3.41	3.95
KSCOWL	2.48	0.07	1.65	0	0.07	3.34	7.62
KSCRAW	3.39	0.01	1.46	0	0.05	4.60	9.52
KSDECA	1.05	0.02	0.02	0	0.03	1.71	2.84
KSDICK	2.69	0.06	1.47	0	0.07	3.39	7.67
KSDONI	1.13	0.05	0.02	1.61	0.00	1.45	4.27
KSDOUG	2.83	0.03	3.23	0	0.01	5.43	11.53
KSEDWA	1.22	0.01	0.26	0	0.01	1.57	3.06
KSELK	0.52	0.00	0.01	0	0.01	0.15	0.69
KSELLI	2.22	0.03	0.13	0	0.08	7.88	10.34
KSELLS	2.48	0.04	0.43	0	0.01	2.48	5.44
KSFINN	4.88	0.00	0.23	0	0.13	9.20	14.43
KSFORD	5.81	0.01	1.15	0	0.12	4.29	11.39
KSFRAN	5.70	0.06	2.61	0	0.01	1.79	10.17

Table 6-1 (Risk Factor Calculation) cont.

Kansas County (KSCNTY)	Highway Risk Factor (RFHW)	Pipeline Risk Factor (RFPL)	Railroad Risk Factor (RFRR)	Waterway Risk Factor (RFWW)	Airport Risk Factor (RFAP)	Fixed Facility (RFFF)	Total Risk Factor (RFTOTAL)
KSGEAR	2.38	0.02	0.20	0	0.06	0.99	3.65
KSGOVE	2.20	0.01	0.13	0	0.01	3.08	5.43
KSGRAH	0.68	0.03	0.01	0	0.04	3.30	4.06
KSGRAN	1.18	0.00	0.04	0	0.01	2.95	4.19
KSGRAY	2.04	0.01	0.18	0	0.01	2.01	4.24
KSGREE	0.66	0.00	0.95	0	0.01	0.58	2.20
KSGREW	2.15	0.10	0.21	0	0.02	0.60	3.08
KSHAMI	1.09	0.00	0.23	0	0.01	0.50	1.83
KSHARP	0.91	0.02	2.14	0	0.04	4.88	7.99
KSHARV	3.48	0.07	1.13	0	0.12	3.18	7.97
KSHASK	1.68	0.02	0.04	0	0.01	3.06	4.81
KSHODG	1.29	0.00	0.00	0	0.00	1.52	2.81
KSJACK	1.40	0.02	0.67	0	0.00	0.77	2.86
KSJEFF	1.56	0.06	2.70	0	0.00	1.19	5.53
KSJEWE	0.88	0.00	0.09	0	0.01	0.87	1.84
KSJOHN	10.06	0.04	10.65	0	0.51	14.88	36.15
KSKEAR	1.26	0.00	0.21	0	0.01	2.45	3.94
KSKING	2.27	0.06	0.01	0	0.03	6.59	8.97
KSKIOW	2.38	0.08	0.75	0	0.02	4.83	8.04
KSLABE	2.79	0.00	1.32	0	0.02	2.43	6.57
KSLANE	0.81	0.00	0.44	0	0.01	3.00	4.27
KSLEAV	2.98	0.06	0.71	0.66	0.04	1.77	6.21
KSLINC	0.93	0.03	0.02	0	0.01	0.45	1.44
KSLINN	1.46	0.10	2.03	0	0.00	0.51	4.12
KSLOGA	1.34	0.01	0.17	0	0.03	1.66	3.20
KSLYON	3.96	0.09	4.22	0	0.05	2.74	11.06
KSMARI	2.45	0.04	1.25	0	0.00	3.31	7.05
KSMARS	1.42	0.01	5.28	0	0.01	2.49	9.21
KSMCPH	3.76	0.20	1.60	0	0.06	7.06	12.68
KSMEAD	2.09	0.04	0.52	0	0.02	4.41	7.08
KSMIAM	2.87	0.17	6.33	0	0.03	2.12	11.52

Table 6-1 (Risk Factor Calculation) cont.

Kansas County (KSCNTY)	Highway Risk Factor (RFHW)	Pipeline Risk Factor (RFPL)	Railroad Risk Factor (RFRR)	Waterway Risk Factor (RFWW)	Airport Risk Factor (RFAP)	Fixed Facility (RFFF)	Total Risk Factor (RFTOTAL)
KSMITC	0.89	0.00	0.04	0	0.04	1.71	2.67
KSMONT	3.08	0.26	4.25	0	0.08	4.95	12.62
KSMORR	1.08	0.05	1.58	0	0.00	0.62	3.33
KSMORT	0.63	0.01	0.02	0	0.02	2.85	3.52
KSNEMA	1.17	0.00	0.01	0	0.01	2.45	3.65
KSNEOS	2.24	0.10	0.95	0	0.07	1.26	4.61
KSNESS	1.15	0.01	0.86	0	0.01	6.11	8.14
KSNORT	1.14	0.02	0.06	0	0.02	1.34	2.58
KSOSAG	2.37	0.06	2.52	0	0.04	1.07	6.06
KSOSBO	0.77	0.03	0.01	0	0.00	1.02	1.84
KSOTTA	3.13	0.11	0.08	0	0.01	0.48	3.81
KSPAWN	1.40	0.01	0.01	0	0.01	1.37	2.79
KSPHIL	1.34	0.01	0.06	0	0.02	2.09	3.54
KSPOTT	1.67	0.00	4.30	0	0.02	3.19	9.18
KSPRAT	2.62	0.09	0.83	0	0.02	5.13	8.69
KSRAWL	1.07	0.02	0.01	0	0.03	0.69	1.83
KSRENO	4.10	0.11	3.28	0	0.14	5.52	13.15
KSREPU	1.51	0.06	0.08	0	0.03	0.85	2.53
KSRICE	1.31	0.08	0.69	0	0.03	4.52	6.63
KSRILE	2.11	0.00	0.00	0	0.13	1.23	3.48
KSROOK	0.92	0.06	0.01	0	0.02	5.04	6.06
KSRUSH	0.98	0.00	0.78	0	0.02	1.65	3.43
KSRUSS	3.21	0.05	0.11	0	0.03	5.58	8.99
KSSALI	3.63	0.08	0.99	0	0.17	3.83	8.70
KSSCOT	1.61	0.00	0.58	0	0.02	1.60	3.81
KSSEDG	8.31	0.12	1.16	0	0.87	35.37	45.83
KSSEWA	3.03	0.02	0.84	0	0.13	14.90	18.92
KSSHAW	5.42	0.08	4.48	0	0.26	9.19	19.42
KSSHEM	0.92	0.00	0.01	0	0.00	1.44	2.38
KSSHER	2.13	0.01	0.05	0	0.05	2.56	4.79
KSSMIT	1.10	0.00	0.06	0	0.01	0.84	2.00

Table 6-1 (Risk Factor Calculation) cont.

Kansas County (KSCNTY)	Highway Risk Factor (RFHW)	Pipeline Risk Factor (RFPL)	Railroad Risk Factor (RFRR)	Waterway Risk Factor (RFWW)	Airport Risk Factor (RFAP)	Fixed Facility (RFFF)	Total Risk Factor (RFTOTAL)
KSSTAF	1.58	0.05	0.21	0	0.01	7.28	9.12
KSSTAN	0.43	0.00	0.04	0	0.05	1.96	2.47
KSSTEV	1.05	0.01	0.02	0	0.01	4.45	5.53
KSSUMN	4.42	0.02	3.44	0	0.01	3.33	11.23
KSTHOM	4.01	0.01	0.04	0	0.02	2.15	6.23
KSTREG	2.04	0.01	0.11	0	0.01	1.91	4.08
KSWABA	1.80	0.06	1.89	0	0.00	0.84	4.59
KSWALL	0.66	0.01	0.12	0	0.03	0.27	1.10
KSWASH	1.48	0.06	2.07	0	0.01	1.70	5.32
KSWICH	0.54	0.00	0.83	0	0.02	1.10	2.49
KSWILS	1.74	0.12	2.50	0	0.01	2.22	6.60
KSWOOD	1.34	0.05	1.85	0	0.00	0.72	3.97
KSWYAN	5.77	0.05	20.53	0.35	0.00	35.05	61.76
MEAN VALUE	2.19	0.05	1.32	0.03	0.05	3.69	7.32

6.3 Vulnerability Factor

The total vulnerability factor (VFTOTAL) varies from a value of 0.06 to 0.57. A listing of vulnerability factors by modes for all Kansas counties and the mean value for each mode is provided in Table 6-2. The vulnerability factor values are mapped on Kansas Counties in Figure 6-3 and Figure 6-4.

The VFTOTAL values show interesting contributions from the vulnerability subfactors. The population of Kansas is mainly concentrated in the east region, with as few as two thousand people living in some of the counties in west. Hence, the population density factor is a predominantly significant contributor towards vulnerability in most parts of eastern Kansas.

But vast areas of farm lands and agricultural lands are located in western Kansas. The weighting assigned to the land use subfactor was therefore a major contributor towards vulnerability, particularly for the counties like Ness, Thomas, Ford and Haskell which have significant agricultural acreage.

Table 6-2
Vulnerability Factor Values for Kansas Counties
(rounded to nearest 1/100)

Kansas County (KSCNTY)	Pop Density VF (VFPD)	Environ-ment VF (VFEN)	Land Use VF (VFLU)	Hosp VF (VFHO)	School VF (VFSH)	Nurs Home VF (VFNH)	Stadiu m VF (VFST)	Prison VF (VFPR)	Water Trmt VT (VFWT)	Vulner Factor (VFTOTAL)
KSALLE	0.01	0.03	0.03	0	0	0.01	0	0	0.01	0.09
KSANDE	0	0.01	0.03	0	0	0	0	0	0	0.06
KSATCH	0.01	0.02	0.03	0	0	0.01	0	0	0.01	0.08
KSBARB	0	0.03	0.06	0	0	0	0	0	0	0.10
KSBART	0.01	0.04	0.07	0.01	0.01	0.01	0	0	0.01	0.15
KSBOUR	0.01	0.01	0.04	0	0	0.01	0	0	0.01	0.08
KSBROW	0.01	0.03	0.04	0	0	0.01	0	0	0	0.09
KSBUTL	0.01	0.02	0.08	0.01	0.01	0.02	0	0.01	0.02	0.18
KSCHAS	0	0.03	0.04	0	0	0	0	0	0	0.07
KSCHAU	0	0.04	0.03	0	0	0	0	0	0	0.07
KSCHER	0.01	0.05	0.04	0	0	0.01	0	0	0.01	0.13
KSCHEY	0	0.02	0.07	0	0	0	0	0	0	0.10
KSCLAR	0	0.02	0.06	0	0	0	0	0	0	0.08
KSCLAY	0	0.03	0.04	0	0	0.01	0	0	0	0.09
KSCLOU	0	0.03	0.05	0	0	0.01	0	0	0	0.10
KSCOFF	0	0.09	0.04	0	0	0.01	0	0	0.01	0.14
KSCOMA	0	0.02	0.04	0	0	0	0	0	0	0.07
KSCOWL	0.01	0.02	0.06	0.02	0.01	0.02	0	0	0.02	0.14
KSCRAW	0.02	0.03	0.04	0.01	0.01	0.02	0	0	0.02	0.13
KSDECA	0	0.02	0.06	0	0	0	0	0	0	0.09

Table 6-2 Vulnerability Factor Values (cont.)

Kansas County (KSCNTY)	Pop Density VF (VFPD)	Environ-ment VF (VFEN)	Land Use VF (VFLU)	Hosp VF (VFHO)	School VF (VFSH)	Nurs Home VF (VFNH)	Stadium VF (VFST)	Prison VF (VFPR)	Water Trmt VT (VFWT)	Vulner Factor (VFTOTAL)
KSDICK	0.01	0.03	0.06	0	0	0.01	0	0	0.01	0.12
KSDONI	0.01	0.07	0.03	0	0	0	0	0	0	0.11
KSDOUG	0.05	0.05	0.03	0.01	0.01	0.02	0.02	0	0.06	0.24
KSEDWA	0	0.02	0.05	0	0	0	0	0	0	0.08
KSELK	0	0.04	0.03	0	0	0	0	0	0	0.08
KSELLI	0.01	0.02	0.06	0	0	0.01	0	0	0.01	0.11
KSELLS	0	0.04	0.04	0	0	0	0	0.01	0	0.10
KSFINN	0.01	0.03	0.1	0.01	0.01	0.01	0	0	0.02	0.17
KSFORD	0.01	0.03	0.09	0.01	0.01	0.01	0	0	0.01	0.15
KSFRAN	0.01	0.04	0.04	0	0	0.01	0	0	0.01	0.11
KSGEAR	0.02	0.09	0.02	0	0.01	0.01	0	0	0.02	0.17
KSGOVE	0	0.02	0.07	0	0	0	0	0	0	0.10
KSGRAH	0	0.02	0.06	0	0	0	0	0	0	0.09
KSGRAN	0	0.02	0.05	0	0	0	0	0	0	0.08
KSGRAY	0	0.03	0.07	0	0	0	0	0	0	0.11
KSGREE	0	0.02	0.07	0	0	0	0	0	0	0.09
KSGREW	0	0.05	0.05	0	0	0.01	0	0	0	0.11
KSHAMI	0	0.02	0.07	0	0	0	0	0	0	0.10
KSHARP	0	0.03	0.06	0	0	0	0	0	0	0.09
KSHARV	0.02	0	0.04	0.01	0.01	0.02	0	0	0.01	0.11
KSHASK	0	0.02	0.05	0	0	0	0	0	0	0.08
KSHODG	0	0.02	0.06	0	0	0	0	0	0	0.09
KSJACK	0	0.03	0.04	0	0	0	0	0	0	0.08
KSJEFF	0.01	0.1	0.03	0	0	0.01	0	0	0.01	0.16
KSJEWE	0	0.03	0.06	0	0	0	0	0	0	0.10
KSJOHN	0.21	0.02	0.04	0.04	0.07	0.08	0	0.01	0.13	0.55
KSKEAR	0	0.02	0.07	0	0	0	0	0	0	0.10
KSKING	0	0.03	0.06	0	0	0.01	0	0	0	0.10
KSKIOW	0	0.02	0.05	0	0	0	0	0	0	0.08

Table 6-2 Vulnerability Factor Values (cont.)

Kansas County (KSCNTY)	Pop Density VF (VFPD)	Environment VF (VFEN)	Land Use VF (VFLU)	Hosp VF (VFHO)	School VF (VFSH)	Nurs Home VF (VFNH)	Stadium VF (VFST)	Prison VF (VFPR)	Water Trmt VT (VFWT)	Vulner Factor (VFTOTAL)
KSLABE	0.01	0.05	0.04	0	0	0.01	0	0	0.01	0.13
KSLANE	0	0.02	0.05	0	0	0	0	0	0	0.08
KSLEAV	0.04	0.03	0.03	0.01	0.01	0.01	0	0.05	0.04	0.21
KSLINC	0	0.03	0.05	0	0	0	0	0	0	0.08
KSLINN	0	0.03	0.03	0	0	0.01	0	0	0	0.08
KSLOGA	0	0.02	0.07	0	0	0	0	0	0	0.10
KSLYON	0.01	0.03	0.05	0.01	0.01	0.01	0	0	0.02	0.13
KSMARI	0	0.04	0.06	0	0	0.01	0	0	0.01	0.12
KSMARS	0	0.01	0.06	0	0	0.01	0	0	0.01	0.09
KSMCPH	0.01	0	0.07	0	0	0.02	0	0	0.01	0.11
KSMEAD	0	0.03	0.07	0	0	0	0	0	0	0.10
KSMIAM	0.01	0.06	0.03	0.01	0	0.01	0	0	0.01	0.13
KSMITC	0	0.06	0.05	0	0	0	0	0	0.01	0.13
KSMONT	0.02	0.02	0.04	0.02	0.01	0.02	0	0	0.02	0.12
KSMORR	0	0.02	0.04	0	0	0	0	0	0	0.06
KSMORT	0	0.05	0.05	0	0	0	0	0	0	0.11
KSNEMA	0	0.03	0.05	0	0	0.01	0	0	0	0.10
KSNEOS	0.01	0.03	0.03	0	0	0.01	0	0	0.01	0.09
KSNESS	0	0.02	0.07	0	0	0	0	0	0	0.10
KSNORT	0	0.03	0.06	0	0	0	0	0.01	0	0.10
KSOSAG	0.01	0.07	0.04	0	0	0.01	0	0	0.01	0.14
KSOSBO	0	0.03	0.06	0	0	0	0	0	0	0.09
KSOTTA	0	0.01	0.05	0	0	0	0	0	0	0.06
KSPAWN	0	0.02	0.06	0.01	0	0	0	0	0	0.09
KSPHIL	0	0.03	0.06	0	0	0.01	0	0	0	0.10
KSPOTT	0.01	0.06	0.04	0	0	0.01	0	0	0.01	0.13
KSPRAT	0	0.03	0.06	0	0	0	0	0	0	0.10
KSRAWL	0	0.02	0.07	0	0	0	0	0	0	0.10
KSRENO	0.01	0.02	0.09	0.01	0.01	0.03	0	0.02	0.03	0.21

Table 6-2 Vulnerability Factor Values (cont.)

Kansas County (KSCNTY)	Pop Density VF (VFPD)	Environment VF (VFEN)	Land Use VF (VFLU)	Hosp VF (VFHO)	School VF (VFSH)	Nurs Home VF (VFNH)	Stadium VF (VFST)	Prison VF (VFPR)	Water Trmt VT (VFWT)	Vulner Factor (VFTOTAL)
KSREPU	0	0.03	0.05	0	0	0.01	0	0	0	0.10
KSRICE	0	0.03	0.06	0	0	0.01	0	0	0	0.10
KSRILE	0.03	0.04	0.03	0.01	0.01	0.01	0.01	0	0.02	0.16
KSROOK	0	0.03	0.06	0	0	0	0	0	0	0.10
KSRUSH	0	0.03	0.05	0	0	0	0	0	0	0.09
KSRUSS	0	0.05	0.05	0	0	0.01	0	0	0	0.11
KSSALI	0.02	0.01	0.05	0.01	0.01	0.01	0	0	0.03	0.12
KSSCOT	0	0.03	0.06	0	0	0	0	0	0	0.09
KSSEDG	0.11	0.02	0.08	0.08	0.07	0.08	0	0.01	0.2	0.57
KSSEWA	0.01	0.02	0.05	0	0	0	0	0	0.01	0.10
KSSHAW	0.08	0.03	0.03	0.06	0.03	0.07	0	0.01	0.08	0.33
KSSHEM	0	0.02	0.08	0	0	0	0	0	0	0.11
KSSHER	0	0.02	0.07	0	0	0	0	0	0	0.10
KSSMIT	0	0.03	0.06	0	0	0	0	0	0	0.10
KSSTAF	0	0.03	0.06	0	0	0	0	0	0	0.09
KSSTAN	0	0.02	0.06	0	0	0	0	0	0	0.08
KSSTEV	0	0.05	0.06	0	0	0	0	0	0	0.11
KSSUMN	0.01	0.03	0.09	0	0.01	0.01	0	0	0.01	0.15
KSTHOM	0	0.02	0.09	0	0	0	0	0	0	0.12
KSTREG	0	0.03	0.06	0	0	0	0	0	0	0.09
KSWABA	0	0.04	0.04	0	0	0	0	0	0	0.09
KSWALL	0	0.02	0.06	0	0	0	0	0	0	0.09
KSWASH	0	0.03	0.06	0	0	0.01	0	0	0	0.10
KSWICH	0	0.02	0.06	0	0	0	0	0	0	0.08
KSWILS	0.01	0.04	0.03	0	0	0.01	0	0	0.01	0.09
KSWOOD	0	0.05	0.03	0	0	0	0	0	0	0.08
KSWYAN	0.3	0.08	0.01	0.05	0.03	0.04	0	0	0.09	0.55

6.4 Risk Index

Risk Index, the product of risk factor and the vulnerability factor, has values ranging 0.04 to a maximum value of 15. Table 6-3 provides a list of Risk Index values for all Kansas counties. It is observed that the calculated risk index is higher in the eastern and the southeastern portion of Kansas than in western part of the state. Major industries are concentrated in these counties. In addition, major transportation corridors run through them. Wyandotte, Sedgwick and Johnson represent the three counties with the highest risk index values. The seven remaining counties in the top ten are Shawnee, Butler, Barton, Douglas, Reno, Finney, and Seward. The highway corridor consisting of I-35 running south from Johnson through Franklin, Butler and Sedgwick counties, represents high risk potential as large quantities of hazardous material are transported through this interstate. Sedgwick County has a large number of fixed facilities and a large population. It also has highway corridors and maximum airplane operations. All these contribute to its high risk index value. The ten counties with the lowest risk index values included Elk, Chautauqua, Wallace, Lincoln, Clay, Osborne, Rawlins, Jewell, Smith, and Hamilton. The risk index values for each county are illustrated in Figure 6-5.

Table 6-3
Risk Index for Kansas Counties

Kansas Counties (KSCNTY)	Total Risk Factor (RFTOTAL)	Total Vulnerability Factor (VFTOTAL)	Risk Index (RI)
KSALLE	4.00	0.09	0.36
KSANDE	4.90	0.06	0.28
KSATCH	5.45	0.08	0.42
KSBARB	8.64	0.10	0.84
KSBART	20.58	0.15	3.06
KSBOUR	4.59	0.08	0.35
KSBROW	5.08	0.09	0.45
KSBUTL	21.65	0.18	3.88
KSCHAS	10.10	0.07	0.74
KSCHAU	1.24	0.07	0.09
KSCHER	5.91	0.13	0.77
KSCHEY	2.24	0.10	0.22
KSCLAR	3.83	0.08	0.32
KSCLAY	1.92	0.09	0.17
KSCLOU	4.11	0.10	0.43
KSCOFF	4.20	0.14	0.59
KSCOMA	3.95	0.07	0.29
KSCOWL	7.62	0.14	1.04
KSCRAW	9.52	0.13	1.22
KSDECA	2.84	0.09	0.26
KSDICK	7.67	0.12	0.90
KSDONI	4.27	0.11	0.48
KSDOUG	11.53	0.24	2.80
KSEDWA	3.06	0.08	0.24
KSELK	0.69	0.08	0.05
KSELLI	10.34	0.11	1.18
KSELLS	5.44	0.10	0.57

Table 6-3 Risk Index Values (cont.)

Kansas Counties (KSCNTY)	Total Risk Factor (RFTOTAL)	Total Vulnerability Factor (VFTOTAL)	Risk Index (RI)
KSFINN	14.43	0.17	2.47
KSFORD	11.39	0.15	1.68
KSFRAN	10.17	0.11	1.14
KSGEAR	3.65	0.17	0.63
KSGOVE	5.43	0.10	0.56
KSGRAH	4.06	0.09	0.37
KSGRAN	4.19	0.08	0.34
KSGRAY	4.24	0.11	0.46
KSGREE	2.20	0.09	0.20
KSGREW	3.08	0.11	0.34
KSHAMI	1.83	0.10	0.19
KSHARP	7.99	0.09	0.74
KSHARV	7.97	0.11	0.85
KSHASK	4.81	0.08	0.38
KSHODG	2.81	0.09	0.25
KSJACK	2.86	0.08	0.24
KSJEFF	5.53	0.16	0.89
KSJEWE	1.84	0.10	0.18
KSJOHN	36.15	0.55	19.91
KSKEAR	3.94	0.10	0.38
KSKING	8.97	0.10	0.94
KSKIOW	8.04	0.08	0.62
KSLABE	6.57	0.13	0.85
KSLANE	4.27	0.08	0.34
KSLEAV	6.21	0.21	1.32
KSLINC	1.44	0.08	0.12
KSLINN	4.12	0.08	0.33
KSLOGA	3.20	0.10	0.32
KSLYON	11.06	0.13	1.45

Table 6-3 Risk Index Values (cont.)

Kansas Counties (KSCNTY)	Total Risk Factor (RFTOTAL)	Total Vulnerability Factor (VFTOTAL)	Risk Index (RI)
KSMARI	7.05	0.12	0.88
KSMARS	9.21	0.09	0.80
KSMCPH	12.68	0.11	1.43
KSMEAD	7.08	0.10	0.70
KSMIAM	11.52	0.13	1.54
KSMITC	2.67	0.13	0.34
KSMONT	12.62	0.12	1.58
KSMORR	3.33	0.06	0.21
KSMORT	3.52	0.11	0.37
KSNEMA	3.65	0.10	0.37
KSNEOS	4.61	0.09	0.42
KSNESS	8.14	0.10	0.85
KSNORT	2.58	0.10	0.26
KSOSAG	6.06	0.14	0.86
KSOSBO	1.84	0.09	0.17
KSOTTA	3.81	0.06	0.24
KSPAWN	2.79	0.09	0.26
KSPHIL	3.54	0.10	0.35
KSPOTT	9.18	0.13	1.20
KSPRAT	8.69	0.10	0.83
KSRAWL	1.83	0.10	0.18
KSRENO	13.15	0.21	2.77
KSREPU	2.53	0.10	0.25
KSRICE	6.63	0.10	0.65
KSRILE	3.48	0.16	0.55
KSROCK	6.06	0.10	0.59
KSRUSH	3.43	0.09	0.29
KSRUSS	8.99	0.11	1.01
KSSALI	8.70	0.12	1.07

Table 6-3 Risk Index Values (cont.)

Kansas Counties (KSCNTY)	Total Risk Factor (RFTOTAL)	Total Vulnerability Factor (VFTOTAL)	Risk Index (RI)
KSSCOT	3.81	0.09	0.34
KSSEDG	45.83	0.57	26.33
KSSEWA	18.92	0.10	1.90
KSSHAW	19.42	0.33	6.46
KSSHEM	2.38	0.11	0.26
KSSHER	4.79	0.10	0.47
KSSMIT	2.00	0.10	0.19
KSSTAF	9.12	0.09	0.87
KSSTAN	2.47	0.08	0.20
KSSTEV	5.53	0.11	0.62
KSSUMN	11.23	0.15	1.73
KSTHOM	6.23	0.12	0.74
KSTREG	4.08	0.09	0.38
KSWABA	4.59	0.09	0.40
KSWALL	1.10	0.09	0.10
KSWASH	5.32	0.10	0.54
KSWICH	2.49	0.08	0.21
KSWILS	6.60	0.09	0.60
KSWOOD	3.97	0.08	0.33
KSWYAN	61.76	0.55	34.13

Figure 6-3

TOTAL VULNERABILITY FACTOR

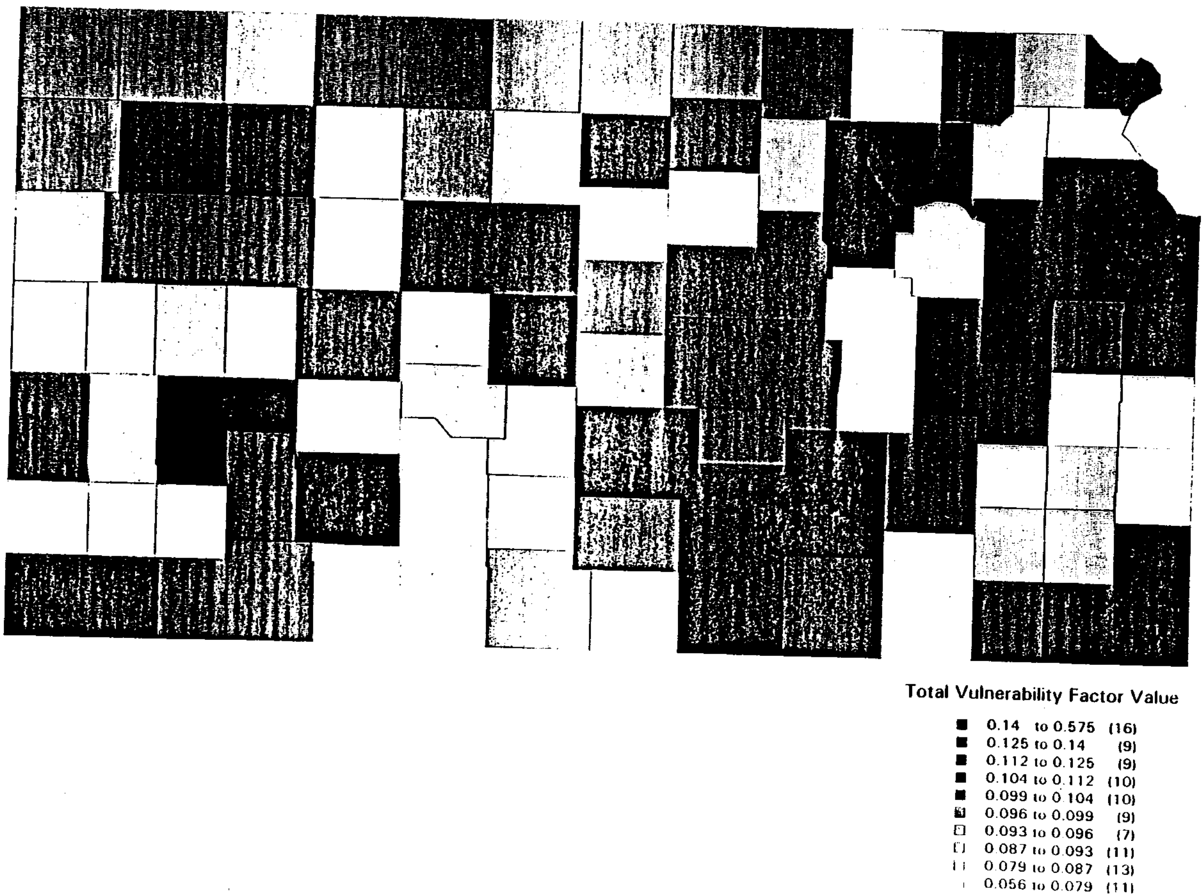


Figure 6-2

TOTAL RISK FACTOR

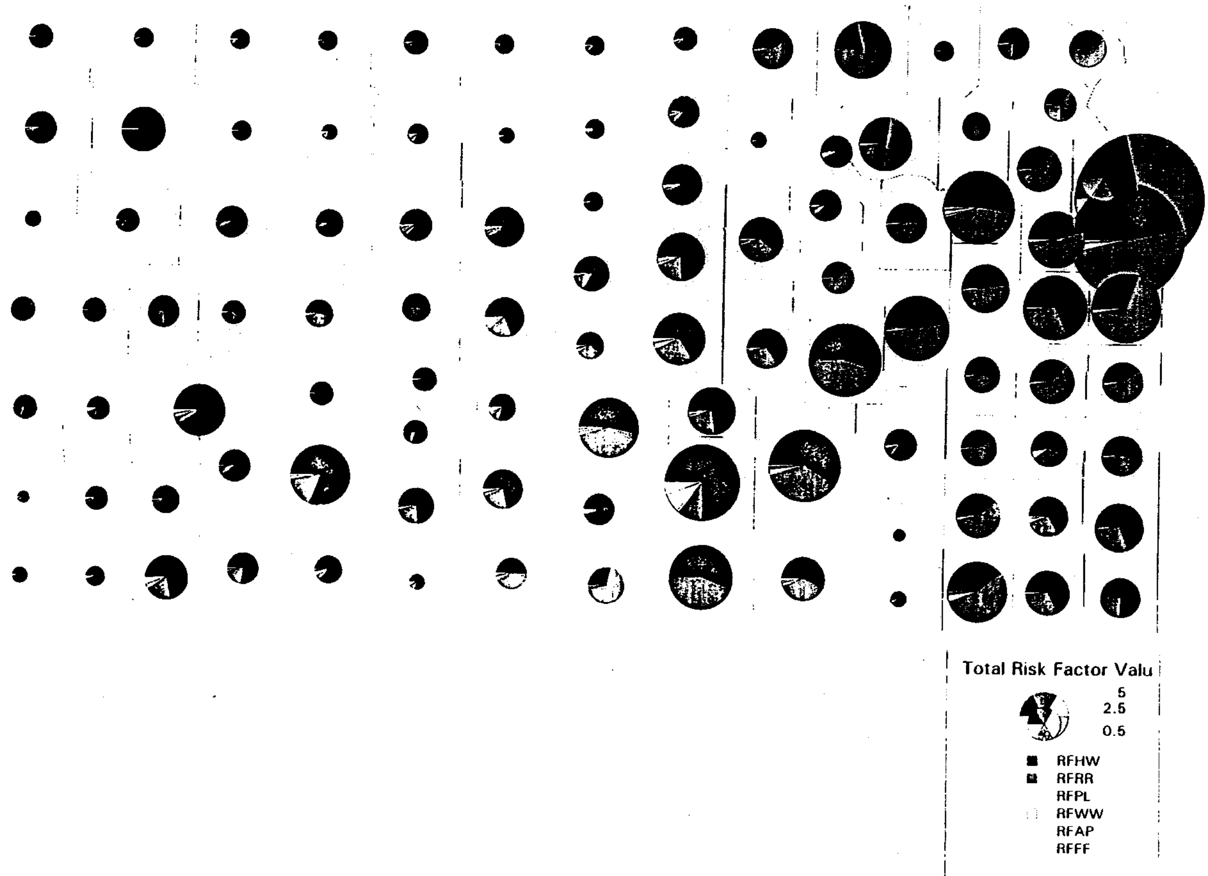


Figure 6-1

TOTAL RISK FACTOR

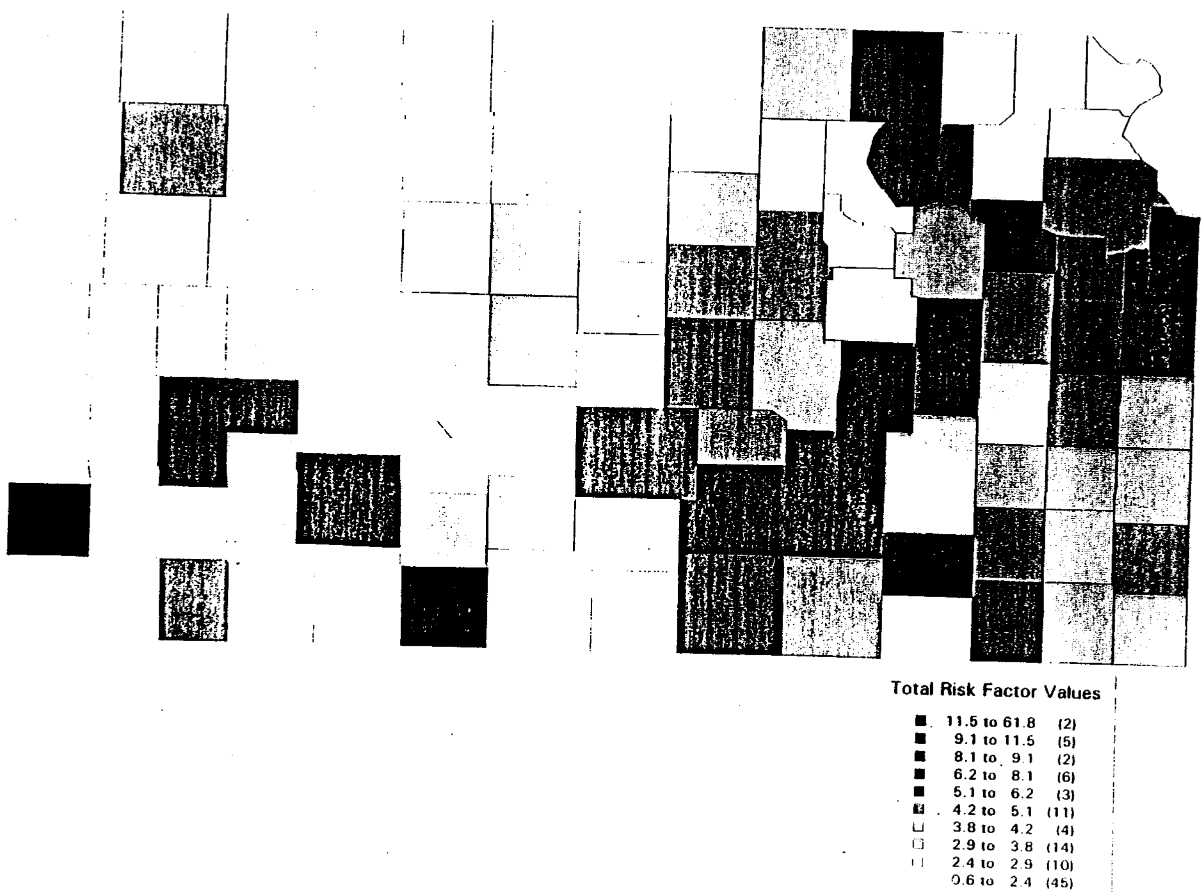


Figure 6-4

TOTAL VULNERABILITY FACTOR

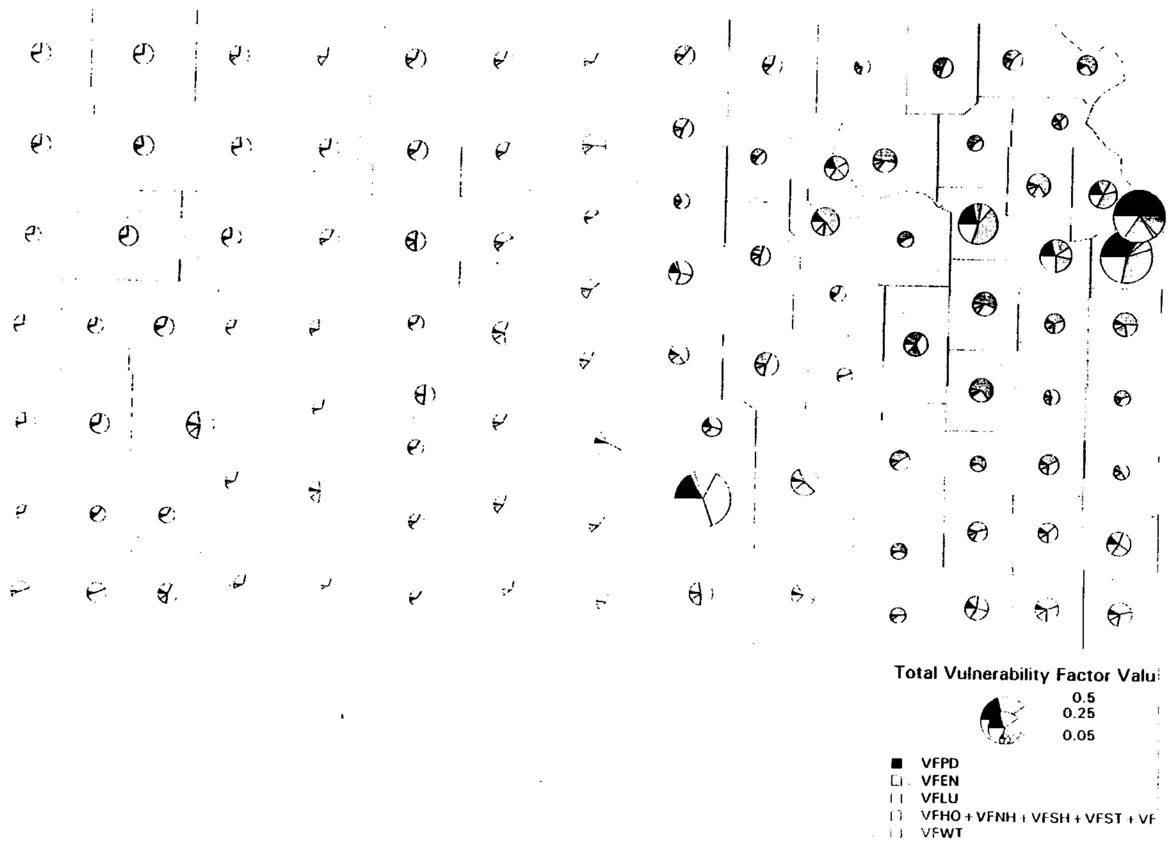
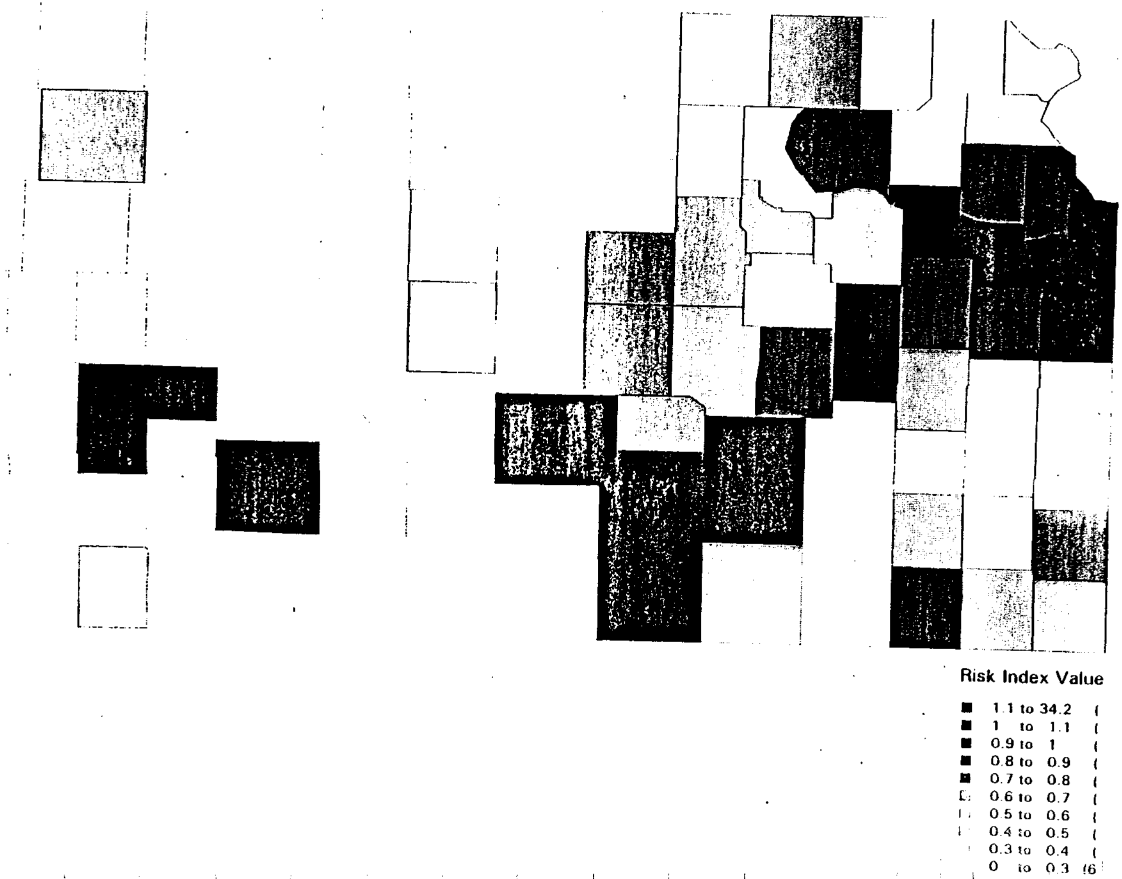


Figure 6-5

RISK INDEX



6.5 Sensitivity Analysis

The parameters incorporated in developing the model are the default values for the current year. They can be changed at any time as circumstances within the state change or as additional or more complete data become available. This feature was used to perform a sensitivity analysis on a number of different elements within the Risk Index model.

Sensitivity analysis is required to test the impact on results, if any of the parameters or variables are assigned different values. It helps in understanding the sensitivity of risk equations to the changes made to individual variables and the overall contribution of that variable to the result.

Model Sensitivity to Chemical Rankings

The project team and advisory committee initially believed that the range for the chemical ranking value (*m1*) should be from 1 to 10 to provide for differentiation among chemicals and their threat to communities. However, no industry-accepted ranking system for hazardous chemicals could be identified to fit this criteria and *Sax's Danger Properties of Industrial Materials* scheme of 0-3 was adopted. Of course, the model can handle a ranking system of 1 to 10 if appropriate justification can be made for such a ranking.

A second issue associated with the *m1* values established in several modes (e.g., highways and waterways) is that there are insufficient data available to identify specific chemicals and their associated rankings with the quantity being moved through each county. In this case, the project team has assigned default values of 2 (medium hazard) as a mean value in these modes until additional data becomes available. These values can be assigned by mode or by specific segment within each mode; e.g., I-70 or any county segment of I-70 could be assigned a specific value associated with the mean value of chemicals traveling along the segment.

It is important to know what the potential impact of the assumption of the default values is on the overall results of the Risk Index since these values must be used until better data become available. For example, if most of the hazardous materials being carried by trucks in the state are actually more hazardous and should be rated as "3," it is useful to know what impact this change in value would produce in the Risk Index.

A sensitivity analysis was conducted to consider the impact of an alternative ranking system for chemicals ($m1$) on the risk factor and ultimately the risk index. This sensitivity analysis was performed first by assigning higher values (scale of 1 to 10) to $m1$ for chemicals transported by trucks on interstates.

The mean value of the risk factor for highways is the highest compared to the mean value of risk factors for all other dynamic modes, representing approximately 30 percent of the total risk factor. When the value of $m1$ for highways was increased to 3, it increased the contribution from highway risk factor to about 33 percent of the total value. When $m1$ was set to an assumed maximum value of 10 (five times the current default value of 2), the resulting risk factor for highways was slightly higher than double the original value. Now, instead of 30 percent of the total risk factor value, the highway risk factor represented 45 percent of the total risk factor from all modes. The summary of the impact of changing the values of *m1* on the risk factor equations is shown in Table 6-4. Increasing the value of *m1* from 2 to 10, the risk factor value for highways is almost doubled and the total risk factor value is increased about one and a half times.

Table 6-4
Sensitivity of the Highway Risk Factor to Changes in m1 Values

Interstate m1	Highway Risk Factor		Total Risk Factor		Highway Risk Factor as a percent of Total Risk Factor
	Max.	Mean	Max.	Mean	
1	7.64	1.93	59.48	7.06	27
2	10.06	2.19	61.76	7.32	30
3	12.47	2.45	64.04	7.58	33
5	17.30	2.97	68.59	8.10	37
7	22.14	3.49	73.14	8.62	41
10	29.38	4.27	79.97	9.40	45

m1 - Chemical Ranking

Shaded values represent current model defaults

Model Sensitivity to Accident Rates

It is interesting to know whether there will be much impact on the risk factor values of different modes of transportation, if the accident rate is doubled on any of these modes one at a time. For the default values of accident rates currently used in the model, fixed facilities have the highest risk factor value, approximately 1.68 times higher than that of the highways. Increasing the accident rate on highways by two times makes the highways more risk prone than other modes. But doubling the accident rate on any other remaining mode would not result in any significant change in the risk factor values, as fixed facilities would still dominate. This is evident by the values shown in Table 6-5. Hence, it can be concluded that the accident rate for any other mode, barring fixed facilities and highways, should increase in future, the relative risk profile would remain almost the same. The total mean risk factor value also does not change significantly.

Table 6-5
Effect of Accident Rates on Mean Risk Factor Values

Mode on which accident rate is doubled	Highway Risk Factor Value	Railroad Risk Factor Value	Pipeline Risk Factor Value	Waterway Risk Factor Value	Airport Risk Factor Value	Fixed Facility Risk Factor Value	Total Mean Risk Factor
Highways	4.38	1.32	0.045	0.030	0.045	3.68	9.5
Railroads	2.19	2.64	0.045	0.030	0.045	3.68	8.63
Pipelines	2.19	1.32	0.090	0.030	0.045	3.68	7.35
Waterways	2.19	1.32	0.045	0.060	0.045	3.68	7.35
Airports	2.19	1.32	0.045	0.030	0.090	3.68	7.35
Fixed facilities	2.19	1.32	0.045	0.030	0.045	7.36	11

Model Sensitivity to Ground/Spill Ratio

The ground/spill ratio is a significant factor in calculating the risk factor. It represents the percentage of the total material spilled on the ground in the event of an hazardous incident. It is erroneous to assume a total spill as it over estimates the impact of spills in specific modes, particularly in fixed facilities because of the enormous quantity of material stored in them. But it is interesting to see the impact of total spill from all other modes, except fixed facilities, on the overall risk factor. The sensitivity of the model is tested by assigning a ground/spill ratio of one hundred percent for all modes barring the fixed facilities. These results of the sensitivity analysis for ground/spill ratio are tabulated in Table 6-6 to illustrate the influence on risk factor.

Table 6-6
Individual Risk Factors as a Percent of Total Risk Factor for Different Ground/Spill Ratios

Mode	Risk Factor as a Percent of Total Risk Factor Value (Default ground/spill ratio)	Risk Factor as a percent of Total Risk Factor (Ground/Spill ratio =100%)
Highways	30	28
Railroads	18	17
Pipelines	0.6	52
Waterways	0.4	0.6
Airports	0.6	0.7

Note: Percents do not total 100 due to the exclusion of fixed facilities from this analysis.

The risk index results changed significantly in that the fixed facilities no longer were the significant contributor to the risk factor value. Pipelines became the highest rated risk, with a risk factor value more than one-half of the total value. This very high risk factor for pipelines when ground/spill is not considered is due to the fact that the quantity considered for pipelines under this scenario includes all material potentially contained in the pipeline within each county. Even though the data are limited for pipelines, this spill rate for pipelines was not evidenced in the Kansas spill data.

CHAPTER 7

CONCLUSION

The risk analysis model is developed through the efforts by the project team over the last one and a half years. It evolved through critique from the advisory panel and input from a number of individuals and organizations. Several professional experts in the hazardous materials field input valuable suggestions and constructive criticism.

The goal to develop a model and microcomputer-based software tool to rate risk and vulnerability to hazardous transportation accidents among Kansas counties was met. Most of the objectives defined prior to the development of the model were achieved. An attempt was made to identify models in peer states for their feasibility for adaptation to Kansas needs. The result of the survey of peer states found no states that had developed a similar model, although some of the work completed in other states did provide some of the basis for the model developed here. The project team compiled databases from all existing sources relevant to the model and converted them to a format consistent with the KRISP application. The KRISP Technical Manual contains complete source data for future updates and descriptions the variables required to drive the model. Finally, a graphics-driven interactive tool that is easy-to-use and provides up-to-date statewide management information was developed and installed at the Kansas Division of Emergency Management.

All suggestions from the Project Advisory Committee were considered an incorporated wherever possible. Generally, those that were excluded lacked sufficient data are could not be supported in the context of the purpose of the model. For example, in the risk factor formula for pipelines, velocity of flow of material and the pressure inside Kansas pipelines are not considered because no data exists. As stated earlier, the parameters like wind velocity, topographical conditions of the state and gradients of the road were not incorporated, since topographical variations among counties throughout the state are moderate. Only those variables that would provide significant differential among counties of state were included. Modal crossings representing a double impact such as railroad grade crossings or an airplane crashing on to a fixed facility were not incorporated into the model. Such incidences or situations are situation specific. This model is not designed to be situation specific; rather, it is intended to give an overall rating among the counties.

The ground/spill ratio (*gs*) is was added to the model after long discussion and consideration in accounting for differential quantities carried and spilled among the modes considered. It was important in calculating a relative risk factor to differentiate among transportation modes. The ground/spill ratio represents the average percentage of the total material spilled on the ground in the event of an hazardous incident. For all modes of transportation, in early versions of the model, it was assumed that everything the carrier transported would spill on the ground during the hazardous material incident. This assumption was utilized originally to err on the conservative side; there were insufficient data for all modes to determine how much is actually spilled in specific incidents. Further, it was thought that if assuming total spill across all modes, the relative impact would be minimized. However, when actual data were applied to the model, it became obvious that using total spill as an assumption was erroneous and significantly overestimated the impact of spills in specific modes, particularly in fixed facilities.

Fixed facilities store huge amounts of materials and assuming a total spill results in a very high risk factor value for fixed facilities compared to any other mode. In reality, while fixed facilities do, on average, spill a greater amount of material, the amount spilled is not proportional to the amount stored. Many fixed facilities, particularly the larger one, must have extensive protective measures in place including trained personnel. In addition, the generally static location of the material enables local response personnel to know what material and how much is stored for advance planning. To maintain consistency in calculating risk for all modes, it became necessary to introduce a ground/spill ratio in risk factor equations for all modes.

The 1994 spill data for Kansas showed a total spill of 168,944 pounds of material from motor carriers involved in 120 incidences. This would result in a spill of approximately 1,400 pounds per incident. Since 40,000 pounds is the base value used in the model as the amount of material carried by a truck, percentage spilled on the ground is 1,400/40,000 or 3.5 percent. But similar reliable data currently do not exist for railroads, waterways and airports in Kansas. There a few entries listed in the Kansas spill database for these modes;

for these modes; either the accident rate is much lower than national estimates, or incidences are under-reported. Hence, in this model, it has been assumed that rail-cars and barges will also result in a spill of 3.5 percent. For an average 6 inch diameter pipe, the ground/ spill ratio was found to be 0.04. For aircrafts too, a ground spill ratio of 3.5 percent was assumed as no information is available currently.

The project team found an extreme need for improvement and standardization of existing data being collected relevant to hazardous materials transportation. Data improvement is important to begin to develop a comprehensive state-wide knowledge of hazardous materials and their transportation in the state. As quantities being transported through the state increase as they are expected to do in the next few years, it becomes even more critical to understand what is being shipped, how much and how frequently it is shipped, along which corridors, and when it is involved in an accident. The framework for the data collection exists; standardization and greater communication among agencies would refine the results of the risk and vulnerability analysis. Specific modes where a refinement of data is desired are discussed in the subsequent paragraphs.

Highways - The only local data used currently in the model are the average daily truck traffic (ADTT) counts. Though the accident rates for the state of Kansas are maintained by Kansas Department of Transportation, no electronic database was available which would assign accident rates to specific highway segments. A database of accident rates (particularly truck accidents involving hazardous materials) attached to each roadway segment in each county would significantly improve the ability to estimate highway risk. Another area where an improvement in data keeping is needed is maintaining a record of the type and quantity of hazardous materials carried by trucks. Trucks must display placards indicating the classification of hazardous material. However, these data are not associated with specific routes, nor are the quantities carried known. Knowledge about the type of material would enable assignment of specific *m1* values in calculating risk factor. Commodity flow studies within Kansas would add significantly to the knowledge associated with hazardous materials movements in the state.

Railroads - The 1993 spill database contains only six entries of incidences involving rail-cars carrying hazardous materials. It is not known how close this number is to actual incidences, although this produces a rate much lower than national averages. Accuracy in spill reporting is essential to calculating a risk index.

Pipelines - Pipelines are one of the safest means of transporting hazardous materials. The 1987 Congressional pipeline safety legislation proposals by USDOT requires periodic inspection and testing of pipelines using hydrostatic tests and instrumented 'pigs'. Pipelines are also equipped with emergency flow-restricting devices. The material spilled on the ground depends on the velocity of flow and the discharge of the material. These parameters could not be incorporated into the model because of the non-availability of such data. Any details about these parameters would refine the model for risk factor equations.

Airways - The least available data was for hazardous materials associated with airports. Contacts made to several local as well as national organizations to obtain the relevant data resulted in no data. No agency that we could identify is keeping track of the type and quantity of material carried by aircrafts in Kansas. A light, double-engine aircraft is the common type used by farmers in Kansas for spraying insecticides and other chemicals; however, there is no reporting associated with these flights. In the model, only jet engine oil used as fuel, is considered as the hazardous material carried by aircraft. The values of *m1* and *m2* are assigned based on this fuel oil alone. However, the model is flexible enough to accommodate additional data whenever they are available, resulting in recalculated risk values based on the material carried, quantities carried, and average amounts spilled in an incident.

Fixed Facilities - To establish a relationship between the quantity of material stored in the facilities and the amount of materials spilled from these facilities, the 1994 spill data base (SARA Title III Spill and Response Report, 1994, provided by Kansas Division of Emergency Management) and the 1993 database of fixed facilities reporting under Section 312 of the Title III Emergency Planning and Community Right-to-Know Act of 1986 were compared. It is found that virtually no fields in the two databases could be used to match or to compare the inventory of fixed facilities with spills reported by these facilities. Out of about 15,000 entries in the 1994 spill database, approximately 70 records matched with the Kansas 312 fixed facility database. It is difficult to match both these records since there are many mismatches between the addresses of the facilities in the two databases. Further, the addresses are difficult to geocode due to non-standard data entry. The SIC codes and the CAS numbers often do not match between the fixed facility database and spill data. Improved coordination between these two databases would result in a significant improvement in data available to improve the risk and vulnerability assessment. If the chemicals were correctly matched by SIC codes or CAS numbers and the facilities by street addresses or by an unique ID, then there would be sufficient representation of the data points to do regression analysis to determine the amount of spills by quantity stored.

In conclusion, the difficult part during the process of developing the model was gathering accurate data in a format that could be incorporated into the GIS environment. There is a lack of reliable data for modeling purposes to identify the flow of hazardous materials by type, quantity and modes. The challenge in developing the risk index model was to develop one sufficiently dynamic to be useful today with available limited data, but which would accommodate data improvements of the future. The large amounts of data associated with a statewide multimodal model have thwarted application at the state level in the past. Now, with a model that incorporates all transportation networks into the risk index and facilitates the complex data management through a geographic information system, a solution is available.

The model is flexible; any locally available data can be incorporated in to it at any time to refine results. The availability of the tool may now provide the incentive to improve data collection procedures and develop greater data collection coordination among reporting agencies.

The risk assessment model developed for the state of Kansas is sophisticated, yet easy to use. It was developed following classical risk theory. MapInfo for Windows™ was the basic GIS platform for this project. The user is able look at the record for any county to check both risk and vulnerability factors. Risk factors for each county and for each mode can be viewed and compared with other counties. Graphical displays enable the user to understand the results very clearly.

Appendix 1
Annotated Bibliography

Hazardous Materials Transportation
Annotated Bibliography

Abkowitz and Associates, Inc. (1994). *Users Guide to HazPlannER.* Nashville, Tennessee.

Abkowitz M.D. and Zografos K.G. (1990). *State and Local Issues in Transportation of Hazardous Waste Material: Towards a National Strategy.* New York: American Society of Civil Engineers

Ashford N., Stanton H.P.M. and Moore A.C. (1984). *Airport Operations.* New York: John Wiley and Sons.

Barge Trips and Tonnage on Missouri River, Mile 367-490 (1994). Navigation Data Center, U.S. Army Corps of Engineers.

Boguslav, Bruce, Strife, Polly T and O'Connel, Philip A. (1986). *Automan : An Information System.* **Recent Advances in Hazardous Materials Transportation Research, State of the Art Report 3.** Transportation Research Board, National Research Council, Washington.D.C., pp.133-137

Summary: The Digital Equipment Corporation, US, has developed AUTOMAN, an automated hazardous materials information system, to provide current regulatory information to all the people involved from purchasing to shipping and receiving personnel. AUTOMAN uses Digital's VAX/VTS Videotex software to provide on-line, real time access to information about hazardous material transportation. Information for a particular product can be accessed through an easy to use menu. AUTOMAN will also provide the generation of required package markings and shipping paper through a database accessed by the Videotex Software. The software allows easy and quick updating of large textural infobases and presents an economical, flexible, easy to maintain means of assembling and disseminating timely and accurate information vital to hazardous material compliance.

A major area of future development is improving and expanding training for shippers and other employees who come in contact with hazardous materials. To this end, a computer based instruction (CBI) is being developed. CBI, in conjunction with classroom training, provides for increased learning experience and frequency of training. CBI allows individuals or groups to have the opportunity to review or learn new material in a multimodal, informal environment. Use of AUTOMAN is included and linked to the CBI course. Benefits have been derived from AUTOMAN in the form of greater efficiency, productivity and reduced risks.

Brogan J.D. and Cashwell J.W. (1985). *Routing Models for the Transportation of Hazardous Materials - State Level Enhancements and Modifications.* Transportation Research Record 1020. Washington, D.C.: Transportation Research Board.

Cashwell, J. W. (1991). *TRANSNET - A Means of Accessing Hazardous Materials Transportation Models and Data Bases.* Sandia National Labs., Albuquerque, NM. United States Department of Energy, Office of Scientific and Technical Information.

Summary: TRANSNET is a compilation of risk and systems analysis codes, routing and cost models and related data that address hazardous and radio active materials transportation. Users may use TRANSNET with a modem equipped personal computer.

TRANSNET is being used to support DOE site environmental analysis, risk assessments and system analyses for the defence and repository programs, routing assessments for the DOE and states and operational analyses as well as basic research.

Descriptions of the models and data bases :

1. SYSTEMS ANALYSIS/RISK CODES:

RADTRAN 4..... It is a computer code for the radiological materials transportation risk analysis. developed by Sandia National Laboratories. It differs from most of the computer codes for risk analysis in that it addresses the transportation related problems of performing a radiological risk analysis with a moving source and of properly distributing the population dose along a route or route segments. It may be used alone for simple O&D calculations or can be used to generate radiological risk unit. The RADTRAN code consists of an incident free module, in which doses resulting from normal transport are calculated and the accident module which calculates accident risks. The code also allows many types of shipment specific and route specific information, including the package behavior data and accident rate data.

WASTES II..... This code is a logistic related tool for use in analyzing the effects of certain policy decisions and/or facility operating schedules for the commercial waste management system. Wastes II uses discrete event simulation techniques to model the generation of spent nuclear fuel, the buildup of spent fuel inventories within the system, and transportation requirements for the movement of wastes throughout the system. The user can specify whether shipments occur optimally, proximally or sequentially.

TRANSIT..... This computerized model evaluates the impacts of transportation upon sitting. It generates isopleths of transportation milage, costs, risks and fleet requirements for shipments to fixed facilities. The model uses the data on location and inventory of material to be shipped. It then overlays a set of grid points across the US to establish equally spaced positions for potential facility locations. The information may be used to graphically display first order estimates of the transportation impacts over time for various regions of the U.S.

2. ROUTING MODELS:

INTERSTAT..... It is an automated modeling system that permits the user to assess the impacts of route specific data on the choice of highway routes. It calculates the routes based upon the minimization of the travel distance, population within one of two band widths along a route and accident rate along a route.

INTERLINE..... It is an interactive computer program that determines likely routes for shipments over the rail road system in the U.S. It further contains the inland waterway network in the U.S. and permits the user to determine potential pathways for use in barge transport.

INTERLINE on TRANSET permits the user to determine the most likely route pathway and calculates the route characteristics including population density along the corridor and pass these data directly to the RADTRAN risk model.

3. DATABASES / INPUT MODELS:

TRANSIS..... This contains the Radioactive Incident Report (RMIR) database initially developed by SNL in 1981. This database currently contains data on approximately 310 transportation and 250 handling accidents and 870 transportation incidents.

RAMPOST..... This data base is a summary of the U.S. DOT radioactive materials postnotification reports for highway route controlled quantity shipments. The DOT maintains these reports in a database entitled RAMRT.

FRTRATE..... FRTRATE (freight rate) models individual shipments of radioactive materials from origin to destination as input by the user. The model estimates shipping costs, package utilization and anticipated lease costs that may be incurred.

TRANSNET access is limited to noncommercial users associated with DOE program activities. Interested users can submit a written request for access, including contact person, sponsor and intended use to :

J.W. Cashwell
Division 6321
Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico.

Cheremisinoff N.P. (1994). *Transportation of Hazardous Materials.* Noyes Publications.

Cheremisinoff N.P. (1995). *Handbook of Emergency Response to Toxic Chemical Releases.* Noyes Publications.

Commodity Flow, DOT Guidance for Conducting Hazardous Materials Flow Studies (1994). Hazardous Material Transportation Act (HMTA) Program.

A Community Model for Handling Hazardous Material Transportation Emergencies (1981). Report # DOT/RSPA/DPB-50/81/30, USDOT, Washington, D.C.

Considine, M. (1986). *Risk Assessment of the Transportation of Hazardous Substances Through Road Tunnels.* **Recent Advances in Hazardous Materials Transportation Research, State of the Art Report 3.** Transportation Research Board, National Research Council, Washington,D.C., pp.178-185.

Summary: Information on the risks to public and the possible damage to tunnel structures from incidents involving the transport of hazardous materials is discussed in this article. The studies were conducted in United Kingdom.

Four tunnels were identified for the study. Two had been in existence for a number of years, the third was approaching the final stages of construction and the fourth was still at the early design stage. The study was broken down into different stages:

* The survey provided information on the type of hazardous material delivered, and in terms of tonnage, petroleum represented approximately 70% of all the goods carried by road. All surveys related to goods transported in bulk and hence provided no information on packaged goods.

* The various mechanisms for causing harm to the people or damage to the tunnel structures and the possible routes where by such harms could be realized in relation to the transport of hazardous substances were identified using techniques of 'fault and event tree analysis'. Such techniques involve the systematic decomposition of an element into combinations of sub events or the consideration of all possible outcomes of a single initiating event. Such a technique revealed that the most important mechanisms by which people or tunnel structures could be affected by various classes of hazardous materials were
- contact with toxic materials: risk to people
- fire: can affect both tunnel and people
- explosion: damage to tunnel and injury to people
- contact with corrosive material- damage to tunnel and injury to people.

Models were developed for consequence analysis. Of the four tunnels selected, differences were observed both in the absolute level of risk and in the relative risks.
From the data collected, frequencies of hazardous events were collected.
By combining the traffic levels, accident frequencies and consequences, risks to people from hazardous materials traffic using the tunnel were determined.

Conclusion: Flammable liquids conveyance was found to account for more than 70% of the risks. It is desirable to examine each particular case on its merit. Structurally, all the tunnel studies exhibited a high degree of resilience and that the chance of tunnel collapse proved very remote.

Countermeasures to Hazardous Chemicals (1990). FEMA RR-34.

Databases Concerning the Transportation of Radioactive Materials. United States Department of Energy, Office of Scientific & Technical Information.

Summary: This article describes two data bases which provide supporting information on radioactive material transport experience in the United States. The RADIOACTIVE MATERIAL INCIDENT REPORT (RMIR) documents the accident experience from 1971 to the present from the data acquired from the US DOT and the Nuclear Regulatory Commission (NRC). The RADIOACTIVE MATERIAL POSTNOTIFICATION (RAMPOST) data base documents the shipments of radio active materials that have taken place.

The DOT regulations specify that a post notification report must be made by the shipper of all shipments of highway route controlled quantities of radioactive materials. These reports for the time period 1987 through Aug. 1990 are contained in a computer data base called

The RAMPOST is a computerized compilation of the shipments that have been completed in the United States since 1982. It contains thirteen fields of information like: Shipment number, origin of shipment, destination of shipment, date of shipment, special types shipments, carrier name, shipper name, consignee name and address, packaging type, radioactive material description, activity of the material being transported, foreign origin of shipment and shipment route description.

These data can be used in environmental analysis, safety analysis, regulatory actions, response to public inquiries and in mitigating institutional concerns.

Dennison, M.S. *Process Safety Management Requirements - A Practical Guide for Compliance.* OSHA and EPA.

Eusebio V.E. and Rindom S.J. (undated). *Rail Movements of Hazardous Materials in Kansas Bureau of Rail Affairs*, Kansas Department of Transportation, Topeka, Kansas.

Fryer L.S. and Kaiser G.D. *DENZ- A Computer Program for the Calculation of Dispersion of Dense Toxic or Flammable Gases in the Atmosphere*. UK Atomic Energy Authority (UKAEA), Report SRD 229.

Granito, John A. (1986). *Strategic Planning for Hazardous Materials Transportation Safety*. Recent **Advances in Hazardous Materials Transportation Research, State of the Art Report 3.** Transportation Research Board, National Research Council, Washington,D.C., pp.201-206.

Summary: Strategic planning is a key factor in increasing the safety of hazardous materials transportation. Careful consideration needs to be given to the organizations that would develop a strategic plan and to the formulation of the goals that would underline the plan and the objectives and tactics that would stem for it. A primary step in planning is setting forth of the organization's mission. Once the mission is defined, goals need to be agreed on and stated. Goals are reached by planned broad considerations for action termed strategies.

Group participation - Those who construct the strategic plan are either in legitimate control of the organization or are appointed by that group. Although unofficial groups may engage in planning, their plans need to include ways of their taking control of the organization that they dispute.

Mitigation - The threats from hazardous materials are substantial. The citizen and the law maker demand increased safety. To achieve some level of perceived performance closer to a zero accident condition requires more than legislation and the enforcement of that legislation. A high level of co-operation is necessary among the subsystems. To manage a safer system, emphasis must be focussed on prevention.

Need for data - Much of the data regarding accidents reveals that the heaviest losses result from rare occurrences. These rare occurrences underscore the difficulty encountered in strategic planning because of the absence of relevant data.

The article also discusses the role of government and industries in strategic planning and favors on creating a safe, timely and affordable National Transportation System for hazardous materials.

Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials, FHWA-SA-94-083, USDOT, FHWA, September 1994.

Harris, N.C., Roadbol, G.G. and Ale, B.J.M. (1986). *Risk Assessment of Alternative Transport Modes for Hazardous Materials.* **Recent Advances in Hazardous Materials Transportation Research, State of the Art Report 3.** Transportation Research Board, National Research Council; Washington, D.C., pp. 47-52.

Summary: A computer based system has been developed by Technical Limited, London, England, for the assessment of risks from process plants. This paper briefly describes the operation of the system and its application to both the existing and the proposed projects, which involve the transportation of hazardous materials. This package can be used in estimating individual and societal risks. It is a powerful tool in comparative assessment of alternatives.

SAFETI is the package developed in this regard, and its objective is to provide:
* Ease of data input (it is an interactive mode)
* Reasonable speed of processing
* Minimum loss of detail
* Variable level of data input / output
* Visibility of both intermediate and final results.

To support an assessment, a wide variety of data files is required. Data is used to generate an 'event file' for failures. These are described by the material escaping, rate of release generated from hole size and operating conditions and the corresponding frequency. Events of approximately similar size can be grouped into one event with a combined probability of occurrence. In the next stage. consequence analysis is done. Toxic and flammable effects are predicted. In the final stage. the impact of this is linked to the human society.

The principal results displayed are:
- Degrees of consequential effect
- Individual risk rates (described by a coded matrix or as iso-risk contours)
- Societal risk (F-N curves; display the frequency F of killing N or more people).

These results can be produced for the whole plant or for parts of it, and in this way, the package is a very powerful tool for comparative work. 100 m by 100 m grid square is used to cover an overall area of 20 km by 20 km.

SAFETI Package used for Transportation - The only fundamental difference when applied to transportation risks is that the source is no longer fixed, but could be anywhere along the route (pipeline, highway, rail road or river). To admit this type of event, a modified events program 'LINEDF' is available. Nodes or co-ordinates of locations, where there are changes in the route directions are input. Special high risk locations like grade crossing can be easily identified. If the overall route length becomes excessive, the cell size can be changed to 200 m by 200 m, allowing the overall area to be increased to 40 km.

Applications of SAFETI in Transportation -
- pipeline designs

- comparison of risks from different modes
- assessment of existing risks in transportation.

Conclusions: SAFETI package can be very effectively used for the assessment of risks in transporting hazardous materials.

At the design or proposal stage, considerable objective information can be obtained that can lead to positive changes in design or proposal. Good quality comparisons can be made which can lead to meaningful decisions.

In case of pipe lines, effect of isolation valve spacing on releases and on risks can be assessed, line diameter can be changed, alternatives of vapor and liquified gas can be examined.

For examination of existing problems, it is possible to make meaningful comparisons using risk-contours and F-N curves and can highlight many of the smaller problems that might otherwise be missed.

This software can take care of meteorology, topography, toxicology and lower flammable limits aspects encountered in the assessment.

It is believed that by using this system, the amount of guess work involved in decision making can be significantly reduced.

Handbook of Chemical Hazard Analysis Procedures, FEMA, USDOT and USEPA (undated).

Hazardous Material Contigency Planning Course (1987). SM 111A, FEMA, USEPA, USDOT.

Hazardous Materials Emergency Planning Guide. (1987). National Response Team.

Summary: This guide will help local communities prepare for potential incidents involving hazardous materials. It describes how to form a local planning team, find a team leader, identify and analyze hazards, identify existing response equipment and personnel, write a plan and keep the plan up to date.

Because emergency planning is a complex process involving a variety of issues and concerns, community planners should consult related public and private sector programs and materials. The following are selected examples of planning programs and materials that may be used in conjunction with this guide.

- FEMA's Integrated Emergency Management System (CPG 1-8) -
  FEMA's Guide for Development of State and Local Emergency Operations plan provides information for emergency management planners and for state and local government officials about FEMA's concepts of emergency operations planning under Integrated Emergency Management System.

- EPA's Chemical Emergency Preparedness Program (CEPP) -
  This program is designed to address accidental releases of acutely toxic chemicals. It increases the community awareness and enhances the local and state emergency planning.

- DOT Materials -
  The U.S. DOT's "Community Team Work" is a guide which discusses hazardous assessment and risk analysis, development of emergency plan and training. DOT's "Emergency Response Guide Book" provides guidance for fire fighters, police and other emergency service personnel.

- Chemical Manufacturers Association's Community Awareness and Emergency Response Program (CMA/CAER) -
  This program encourages the chemical plant managers to take the initiative in cooperating with local communities to develop integrated emergency plans for responding hazardous materials incidents.

In chapter 2, this Planning Guide describes how communities can organize a planning team. Experience shows that plans are not used if they are prepared by only one person or by only one agency. Emergency response requires trust, coordination and cooperation among responders who need to know who is responsible for what activities and who is capable of performing these activities. This knowledge is gained only through interaction. Working together in developing and updating plans is a major opportunity for cooperative interaction among responders.

Chapter 3 describes the tasks of the planning team which include :
Review of the existing plans, hazards analysis, assessment of preparedness, prevention & response capabilities and Development of an ongoing program.

The next chapter describes two basic approaches to writing a plan. (1) Development or revision of a 'hazardous materials appendix' to a multihazard EOP following the approach described in FEMA's CPG 1-8 and (2) development and revision of a 'plan covering only hazardous materials'.

In the following chapters, this guide, presents and discusses a list of planning elements related to hazardous materials incidents. Communities that are developing a hazardous materials plan, need to review these elements. The means by which the plans can be reviewed systematically is also presented.

Conclusion: The Hazardous Materials Emergency Planning Guide is prepared with the following objectives in mind :

- Focus community activity on emergency preparedness and response
- Provide communities with information in organizing the planning task
- Furnish criteria to determine risk and to help communities decide whether they need to plan for hazardous materials incidents.
- Help communities conduct planning that is consistent with their needs and capabilities
- Provide a method for continually updating a community's emergency plan.

Hazardous Materials Transportation Safety Act of 1990, Section 1801, P.L. 101-615(1990).

Hazardous Materials Shipment Information for Emergency Response, Special Report 239, Transportation Research Board, Washington, D.C. 1993.

Hazardous Material Transportation Emergencies: A Planning Guide. New York State Study.

Hazardous Materials Transportation Study Report, Minnesota Emergency Response Commission. Department of Public Safety, June 1994.

Hobeika, Antoine G., Jamei, Barnham and Santoso, Iwan B. (1986). *Selection of Preferred Highway Routes for the Shipment of Spent Nuclear Fuel Between Surry and North Anna Power Stations in Virginia*. **Recent Advances in Hazardous Materials Transportation Research, State of the Art, Report 3**. Transportation Research Board, National Council Research, Washington D.C., pp.67-73.

Summary: The Virginia Electric and Power Company has proposed to transport irradiated nuclear fuel from its current storage location at surry to its North Anna Station. Eight feasible routes were proposed for the shipment. The methodology used for selecting the routes were based on US DOT guidelines. But several modifications and additions were incorporated to the DOT guidelines to enhance their applicability.

Some of the problems in transporting the hazardous materials depend upon the characteristic of the vehicle, operator, methods in which the materials are handled and packaged, rad way design, emergency response and preparedness to accidental releases. One of the methods to improve safety is to reduce the potential exposure of public health and property to accidental releases of these materials. This could be done by selecting the most preferred routes to transport the hazardous materials.

The DOT guidelines evaluate the route comparison based on the following classification:
1. Primary risk factors
- Normal radiation exposure
- Public health risk
- Economic risk
2. Secondary factors
- Emergency response capabilities
- Evacuation capabilities
- Location of special facilities
- Traffic facilities and injuries

The selection of route is chiefly based on the primary risk factors and the secondary factors can be used if no clear cut choice emerges from the evaluation of primary factors.

Framework of Analysis-
To determine the preferred route and alternative routes for highway, a conceptual approach is developed based on Feasibility, Evaluation and Choice.

Modification of DOT guidelines :
* Radiation Risk - Since it has been proved that the inhalation dose of the radio active material is highly dependent on the direction of wind, wind rose data was used for each segment of the road.
* Economic Risk - Decontamination cost was determined for the vacant land, as an additional factor. Wind factor was also added to economic risk.
* Special Facilities - The DOT methodology was further modified by the addition of road way geometrics comparison factor.
* Emergency Response - A formula was developed to determine the emergency response effectiveness.
* Transportation Cost - It was determined through actually driving along the route and by public response through a questionnaire etc.,.

Conclusion: The following recommendations were suggested for extra safety:
1. Two escort vehicles, one in front and the other in the back of the truck, must accompany the shipment.
2. Shipment during peak traffic hour should be avoided.
3. Shipment during night times should also be avoided.
4. Emergency response capabilities for counties and cities along the recommended route should be improved.

Holmes J.M. and Byers C.H. (1990). *Counter Measures to Hazardous Chemicals*', Report # RR-34.

Kansas Aviation Systems Plan (1992, January). Kansas Department of Transportation, Division of Aviation, Topeka, Kansas.

Kessler, Dan (1986). *Establishing Hazardous Materials Trucks for Shipments through the Dallas-Fort Worth Area.* **Recent Advances in Hazardous Materials Transportation Research, State of the Art Report 3.** Transportation Research Board, National Research Council, Washington,D.C., pp.79-87.

Summary: The purpose of this study is to develop a system of regional hazardous materials truck routes for shipments through the Dallas-Fort Worth Area. The approach was based on the risk assessment methodology, outlined in FHWA Guidelines. This document provided the basic frame work for evaluating alternative highway routes for hazardous material truck shipments.

The risks are associated with the quantities and the type of shipment. The risk may be calculated by estimating the probability of on an accident on that segment and the consequences of that accident. should it occur. These two variables are then combined to establish a total risk measure referred to as 'population risk'. By summing up these specific risk measures along each alternative route , a total risk value can be established for each route. The route with the lowest risk value may then be determined.

Designating routes for hazardous materials shipment is only one means of reducing the potential risk. Clearly program involving vehicle inspection and maintenance, vehicle operator training and licensing and upgraded emergency response capabilities should be pursued to reduce the risk and improve public safety.

Lautkaski, Risto. (1986). *Use of Risk Analysis in Enhancing the Safety of Transporting Hazardous Liquified Gases.* **Recent Advances in Hazardous Materials Transportation Research, State of the Art Report 3.** Transportation Research Board, National Research Council; Washington.D.C.. pp. 59-63.

Summary: The paper discusses the risk analysis performed on land transportation of hazardous liquified gases in Finland. It summarizes the factors contributing to the accident risk and a number of suggestions and measures in reducing these risks.

The Technical Research Center of Finland conducted a research in assessing the risks involved in transporting hazardous materials. The team performed a probabilistic risk analysis. Computer codes using the finite element method were utilized in the calculation of stresses caused by the internal pressure and external loads. Following problems were emerged from the discussions:

How effective are the new curved steel plates, without supporting bars, which replaced the old thick steel plates with bars, used in pressure vessels, in preventing tank head punctures?

A pneumatic type of loading valve, which has the safety feature of closing when its outer part is broken, was introduced. Will the new valve enhance the transportation safety too?

A wagon of the train carrying a toxic material must not be coupled directly with a locomotive or a wagon loaded with flammable materials. Are these restrictions sufficient?

Puncturing the tank was regarded possible only in violent collisions. However in large stations and yards where trains move at reduced speeds, tank puncture was not considered possible. Is this assumption reliable?

Railway accidents were classified into different categories. This is because a sharp or rigid object capable of damaging the tank is different in different accidents. Besides, the consequences of a spill will be on a different scale for accidents that occur on line. Three different categories used for accidents were:

1. Accidents that occur on line - collisions, derailments, level crossing accidents.
2. Accidents that occur at stations - collisions, switching accidents
3. Categories of random failures - Leakage in a moving tank wagon. leakage in a stationary tank wagon.

The estimation of the probabilities of the key accidents required a large number of qualitative and quantitative data on the transportation system. The qualitative data include the characteristics of railway sections, single or double track, characteristics of level crossings and type of signal boxes at stations. The quantitative data include the arrival and departure times of trains, number of crossing and passing trains, total length of the line in excavation and on bridges and road traffic densities at level crossings.

The damage modes considered were :

* Impact on tank head, tank side and valve group
* puncture
* crushing
* overheating during a fire

The failure modes considered were:

* endurance or corrosion failure of the tank
* valve failure

The suggestions proposed for reducing the accident risks were:

* Construction of the manway nozzle in transportation pressure vessels
* Installation of head shields and buffer override restraints
* Positioning of tank wagons carrying hazardous material like liquified gases, in the middle of the train.

Lepofsky M., Paul Der Ming Cheng and Meyer J.E. (1993). *Route Determination Using Population Miles of Exposure.* Abkowitz and Associates, Inc., Tennessee.

Lewis R.J., Sr., *'Sax's Dangerous Properties of Industrial Materials'*, Van Nostrand Reinhold, New York, CD-ROM, 1994.

Logistics for Hazardous Materials Transportation: Scheduling, Routing and Siting (1990). USDOT Interim Report.

Mileage and Travel Tables (1993). Kansas Department of Transportation.

O'Driscoll, J.J. (1986). *Development of a Universal Emergency Action Guide System to Enhance Response Effectiveness and Safety.* **Recent Advances in Hazardous Materials Transportation Research, State of the Art Report 3.** Transportation Board, National Research Council, Washington,D.C., pp.130-133.

Summary: During the last 20 years, a number of catastrophic incidents have occurred during transportation, manufacture and use of hazardous materials. The Jody Chart System provides basic key information of major hazardous potential of the materials under various actual circumstances that could be involved. This information is a supplement to the US DOT Emergency Response Guide Book, and allows response personnel to know immediately the major catastrophic potentials of materials involved in the incident, as well as provides an indication of the multiple hazards some materials present.

The article identifies the characteristics and properties of hazardous materials that need recognition and details about the hazard potentials involving these materials. It also lists the type of accidents that are likely to occur and their critical conditions. These hazardous materials are given a two-letter codes for rapid notation. Use of these codes allows response personnel to know immediately the major catastrophe potentials of materials involved in the incident. Use of the hazardous codes also provides an indication of the multiple hazards some materials present. The abbreviations for major hazard potentials are easily remembered during actual emergency situations by trained personnel and provide the necessary information to permit proper response measures to be taken.

Parker S.A. (1994). *An Assessment of US Hazardous Materials Emergency Response Preparedness'*, Master of Science Thesis, Tennessee: Vanderbilt University.

Paul W.H. and Radnor P.J. (1979). *Highway Engineering* , New York: John Wiley and Sons, Inc. p 73.

Pijawka K.D., Foote S. and Soesilo S. (1985). *Risk Assessment of Transporting Hazardous Material: Route Analysis and Hazard Management.* Transportation Research Record 1020. Washington, D.C.: Transportation Research Board.

Pipelines and Public Safety, Special Report 219 (1988). Washington, D.C.: Transportation Research Board, National Research Council.

Raj, Phani K. and Theodore S. Glickman, Theodore S. (1986). *Generating Hazardous Material Risk Profiles on Railroad Routes.* **Recent Advances in Hazardous Materials Transportation Research, State of the Art Report 3.** Transportation Research Board, National Research Council; Washington, D.C., pp. 53-59.

Summary: This paper deals with the approach for the generation of a risk profile of the rail transportation of any hazardous material on any route. It highlights the risks of accidents involving larger releases (collisions and derailments on main lines and in yards). Risk profiles for various hazardous materials or for various routes can be combined. The approach uses a specially developed model for the probability distribution of the number of cars experiencing a release in such an accident. The effects are combined with the population exposure estimates in order to estimate the fatality levels.

Collisions and derailments cause the release of hazardous materials along a particular route. These are less frequent but most severe and the results are given in the form of a risk profile, which is a plot of frequency v/s consequences. Consequence is the number of fatalities due to the effects of a release and corresponding frequency is the number of accidents per year in which that consequence is equalled or excelled.

The approach is based on the number of cars that release the hazardous material in an accident. When the frequency and the consequence have been estimated for every segments, for every possible car that would release the hazardous material, the co-ordinates of each of the points on the risk profile are determined. Each point corresponds to a different value for the number of cars that release their contents.

The expected frequency per year of accidents in which a particular hazardous material is released from a given number of cars on a particular route segment i estimated from the overall expected frequency per year of accidents and the probability that the material is released from that number of cars. The results are then summed over all the route segments.

The article gives a large number of formulae for calculating the frequency based on the probability of cars releasing the hazardous material. A sequential approach is adopted in computing the probability distribution which has the advantage that sensitivity analysis can be performed later, by varying any of the probability distribution to represent different accident scenarios.

Estimation of consequences - The magnitude of the consequence is estimated by multiplying the expected density of the population in that area by the size of the lethal area. Estimation of the lethal areas for chlorine and LPG are detailed in the article.

Conclusion: The model described is applied to a route on which chlorine and LPG are transported. The approach relies on a number of consequence models for the various scenarios under which the hazardous materials of interest may be released in an accident.

Rhyne W.R. (1994). *Hazardous Materials Transportation Risk Analysis*. New York: Van Nostrand Reinhold.

Right -To - Know Program. (1992). Bureau of Environmental Health Services, Kansas Department of Health and Environment, Annual Report. Topeka, Kanss.

Risk Assessment / Vulnerability Users Manual for Small Counties and Rural Areas. Report # DOT /OST/P-34 / 86-043, USDOT, March 1984.

Roskam, Jan. (1989) *Airplane Design - Part 1: Preliminary Sizing of Airplanes*, The University of Kansas, Lawrence.

Saccomanno F.F., Yu M. and Shortreed J.H. (1985). *Risk Uncertainity in the Transport of Hazardous Materials* ', Transportation Research Record 1383. Washington, D.C.: Transportation Research Board.

Scanlon R.D. and Cantilli E.J. (1985). *Assessing the Risk and Safety in the Transportation of Hazardous Materials* ', Transportation Research Record 1020. Washington, D.C.: Transportation Research Board.

Soloway J. (1993). *What is Risk?* Consensus Report, International Consensus Conference on Risk of Transporting Dangerous Goods, University of Waterloo, Ontario, Canada.

ISBN 0-9696747-0-8.

Starry C. and Stock W. (1995). *Alternative Modeling Approaches for Allocating Truck Flows of Hazardous Chemicals.* Transportation Research Board, 74th Annual Meeting, Washington. D.C.

State-Wide Radioactive Materials Transportation Plan, Phase I and II. (1989, December). Nevada Department of Transportation.

Taylor J.R.. (1994). *Risk Analysis for Process Plant, Pipelines and Transport.* E&FN Publications.

Technical Guidance for Hazard Analysis (1987). USEPA, FEMA, USDOT.

U.S. Department of Transportation (1983). *Risk Assessment/Vulnerability Validation Study Vol.2 Appendices: 11 Individual Studies.* Office of the Secretary of Transportation.

Summary: The risk assessment manual is intended for use in communities whose population is less than 50,000. The primary objective is to alert the officials of these communities to the threat of life. property and environment from the transportation of hazardous materials. It is then left to the community officials to decide how best the risk could be reduced.

This manual provides a simple model to assess the risk and vulnerability from the transportation of hazardous materials. A 'model' may be thought of a series of logical steps to follow that will lead to better decisions.

In order to assess the risk of a community, it is first necessary to determine the quantity and nature of the materials. All the interstate carriers carrying the hazardous materials must display clearly the type of material they are carrying. It is a federal law that all these vehicles must have 'Placards'. It is also advisable to collect data on the records of past hazardous materials incidents in the community. This will give an idea about the magnitude of danger involved in handling them.

The steps to be followed in the assessment of risk are as follows:

Step 1: Collecting maps and aerial photographs - the community maps will identify routes of all form of transportation.
Step 2: The survey of the manufacturing and storage establishments that handle the hazardous materials is needed.
Step 3: Obtain traffic data on pipe lines, barges, air and rail.
Step 4: Plot one mile route segment corridors on maps.

Step 5: Indicate each of the manufacturing and storage establishments with a dot on the maps where they actually exist.
Step 6: The final data gathering step is to conduct traffic survey.
Step 7: Determine risk sub factors- count the total number of vehicles transporting the hazardous materials in all transportation modes (count one vehicle for each 1/10 mile of pipe line). Also, calculate the total route milage.
From the Total Carrier Count (TCC) and the Total Route Milage(TRM), find out the Twelve Hour Average Density (THAD) using Table 1. (Note: If THAD > 100, set the Risk Factor to 1.0)
Next, find the Average Form of Threat(AFT) making use of Table 2-Vehicle Table and Table 3- Forms of Threat Table.
Step 8: Use the Risk Factor Table (Table 5a) to determine the community's Risk Factor from the THAD value AFT value.
Step 9: Determine the consequence sub factor - several factors determine the consequences of hazardous accident:

(a) Population density - Finding the average population density and using Table 6. determine the Population Density Value.
(b) Environment Sub factor - Find the average percent of waterway and using Table 7, determine the Environment value.
(c) Property Sub factor - Determine the average property value of the community by using Table 8.
(d) Manufacturing and storage - Determine the Establishment value using Table 10.

Step 10: Determine "Consequence Factor" by summing up the values of (a) thru (d) in the above paragraph.
Step 11: Determine the Risk Index by multiplying the Risk Factor by Consequence Factor. From the value of Risk Index obtained, determine the Level of Risk using Table 11.
Step 12: Determine the Level of Preparedness - this is done by evaluating the questionnaire, answered by the community under consideration (Note: Questionnaire sample is also provided in the manual) Use Table 12 to determine Level of Preparedness.
Step 13: Determine Community Vulnerability by utilizing the values of level of risk and preparedness and using Table 13.
Step 14: Select a Response Plan - Depending on the resources available to any given community, the risk index achieved by the manual, a suggested level of plan can be adopted to cope with the potential hazardous materials.

Conclusion: This manual provides a simple, easy to understand model to assess the risk involved in transporting the hazardous materials. This manual has been effectively used in evaluating the risk, in many small communities and rural areas. The study conducted in about 8 of the rural areas, is described in detail in the next edition of the report titled ' Risk Assessment / Vulnerability Users Manual for Small Communities and Rural Areas' , US Dept. of Transportation, Revised Edition, March 1986.

Weidenhamer G.H. and Vesely W.E. (1994). *Recent Research Efforts at the NRC on the Application of Risk Based Approaches*. SERA-Vol 2, Safety Engineering and Risk Analysis.

Zajic, J.E. and W.A. Himmelman (1978). *Highly Hazardous Materials Spills and Emergency Planning*. New York: Marcel Dekker, Inc.

Project Goal

To develop a model and microcomputer-based software tool to rate risk and vulnerability to hazardous transportation accidents among Kansas counties for strategic placement of response resources.

Project Objectives

- Identify models in peer states and the feasibility for adaptation to Kansas needs;
- Compile databases from existing sources, including national, state, and local agencies;
- Develop a graphics-driven interactive tool that is easy-to-use and provides up-to-date statewide management information.

Project Tasks

Task 1 Literature review

Task 2 Peer State Assessment

Task 3 Solicit input from state and local emergency preparedness teams

Task 4 Risk and Vulnerability Model Development

Task 5 GIS Application Development

Task 6 Software Application Field Test

Task 7 Final Report

KANSAS
HAZARDOUS MATERIALS TRANSPORTATION RISK AND VULNERABILITY ASSESSMENT TOOL

Section 1815 of the Hazardous Materials Transportation Uniform Safety Act of 1990 (P.L. 101-615) provides funds to develop, improve and implement emergency plans which includes:

- ✔ determining movement patterns of hazardous materials within and between states

- ✔ determining the need for regional hazardous materials emergency response teams.

Literature Review Summary

1. Risk and vulnerability factors in transportation of hazardous materials

2. Existing risk and vulnerability models

3. Hazardous materials transportation databases

4. Computer packages applied in hazardous materials transportation management.

Project Assumptions

- ✔ Input from the key state agencies represented on the Kansas State Emergency Response Commission and local emergency response committees essential to development of a useful planning tool.

- ✔ Key factors to risk and vulnerability assessments exist in sufficient form within these agencies and that original data collection will not be required to develop the assessment tool.

- ✔ The management tool will be designed to accept data enhancements as data collection is improved.

- ✔ Project output will be provided in a form that is interactive and easy-to-use by state management and will serve as an on-going management information tool.

Kansas Hazardous Materials Transportation
Risk and Vulnerability Assessment
Advisory Committee

Kansas Division of Emergency Preparedness
2800 S.W. Topeka Blvd.
Topeka, Kansas

Wednesday, April 26, 1995
9:00 a.m. - 12:00 noon

Agenda

9:00 a.m.	**Introductions and Meeting Objectives**
9:15	**Model Revisions Suggested by Advisory Committee** Revisions Implemented Model Limitations
9:45	**Model Results: Data Inputs and GIS Demonstration**
10:15	Break
10:30	**Model Results** (cont.)
11:30	**Tasks Remaining and Project Scheduling** Documentation Training Revisions Final report
12:00	Adjourn

Role of the Advisory Committee

The assessment models must be based on the needs and knowledge of the agencies involved in the hazardous material transportation safety process.

Three meetings of the task force:

- ✔ identify the key risk and vulnerability factors and data resources
- ✔ review the workplan and draft models
- ✔ present the final product.

Hazardous Materials Transportation Risk and Vulnerability Assessment

Task Status

Task 5 GIS Application Development

- Prepare user's guide
- Data dictionaries: data sources and variable description

Task 6 Software Application Field Test

- Additional training to KDEP staff
- Program revisions as necessary

Task 7 Final Report

- Complete final report which documents literature review, peer state review, data collection sources, model development and results.

Kansas Hazardous Materials Transportation Risk and Vulnerability Assessment Advisory Committee

Kansas Division of Emergency Preparedness
2800 S.W. Topeka Blvd.
Topeka, Kansas

Wednesday, February 1, 1995
9:00 a.m. - 12:00 noon

Agenda

9:00 a.m.	Introductions
9:15	**Project Overview** Review of Project Goals Meeting Objective Task Status
9:30	**Model Development** Structure of the Model Assumptions Model Limitations and Recommendations
10:30	Break
10:45	**Model Results: Data Inputs and GIS Demonstration** GIS Process Overview GIS Outputs User Interface

Hazardous Materials Transportation
Risk and Vulnerability Assessment Tool

Advisory Committee Questions

Highways: Accident rate multiplier for highways? Attached to segment rather than county.

Railroad: Double reporting under fixed facilities and yards?

Pipelines: Flow process, detection and isolation of leak

Airport data: Strategy for including airline cargo?
Approaches around airports

Fixed facilities: m_1 - Basis for assignment and overall range
Toxicity - use of *Sax's Dangerous Properties of Industrial Materials* and *Hawley's Condensed Chemical Dictionary*

Use of weight rather than volume

Vulnerability: Area of influence
Normalized for size of county, relative to square miles
Inclusion of prisons and water treatment

ArcInfo integration

County level output information

Project Goal

To develop a model and microcomputer-based software tool to rate risk and vulnerability to hazardous transportation accidents among Kansas counties for strategic placement of response resources.

Project Objectives

- Identify models in peer states and the feasibility for adaptation to Kansas needs;
- Compile databases from existing sources, including national, state, and local agencies;
- Develop a graphics-driven interactive tool that is easy-to-use and provides up-to-date statewide management information.

Project Tasks: Current Status

Task 1 Literature review
Complete

Task 2 Peer State Assessment
Complete

Task 3 Solicit input from state and local emergency preparedness teams
On-going
Schedule next committee meeting

Task 4 Risk and Vulnerability Model Development
Final revisions

Task 5 GIS Application Development
On-going

Task 6 Software Application Field Test
Planned to begin mid-March
Final revisions - May/June

Task 7 Final Report
July, 1995

Appendix 3
Ground/Spill Ratio Calculations

GROUND/SPILL RATIO CALCULATIONS

HIGHWAYS

Consider a 30 mile segment with an Average Daily Truck Traffic of 400.

Total amount of hazardous material involved in spill per year =

$HW_{sp} * HW_{hc} * HW_{sr} * ADTT * L * m1 * m2 * 365$

$= 0.2 * 0.04 * 2*10^{-6} * 400 * 30 * 1 * 40{,}000 * 365$
= 2800 pounds/year

Number of all accidents per year $= 2*10^{-4} * 400 * 30 * 365$
= 8.76

Number of hazardous material accidents per year = 0.04 * 8.76
= 0.35

Number of hazardous material accidents resulting in spill per year = 0.2 * 0.35
= 0.07

Amount of hazardous material potential for spill per year = 2800/0.07 = 40,000 lbs/accident

From 1994 Spill database,
Amount of hazardous material spilled per accident = 1,400 lbs

Ground-Spill ratio = (1,400/40,000) * 100 = 3.5 %

PIPELINES

Consider an average 6 inch diameter, 30 mile long pipeline.

Amount of hazardous material involved in spill =

$3.14 * (\text{Diameter})^2/4 * \text{length} * \text{unit wt. of material}$
= 3.14 *(5.5)2 * 30 * 50 *5280/144
= 1306706.2 lbs

Number of hazardous material accidents per year $= 1.5 * 10^{-3} * 30$
= 0.045

Since spill probability is 100%,
Number of hazardous material accidents resulting in spill per year = 0.045

Amount of hazardous material potential for spill per accident = 1306706.2 / 0.045
= 29037915 lbs / year

From 1994 Spill database,
Amount of hazardous material spilled per accident = 12,000 lbs
Ground-Spill ratio = (12,000 / 29037915)*100
= 0.04 %

Appendix 4
Calculation of Weight Adjustment Factors

CALCULATION OF WEIGHT ADJUSTMENT FACTORS

1. HIGHWAYS

Average weight of hazardous materials carried by a truck = 40,000 lbs
Weight adjustment factor = 1

2. RAIL ROADS

Weight of an empty box car = 40 tons
Weight of a loaded box car = 85 tons
On an average, about 60% of the car is filled and 40% is empty.
Average weight of box car = 0.60 (85) + 0.40 (40) = 67 tons
Average weight of material carried by a box car = 67 - 40 = 27 tons = 54,000 lbs
Weight adjustment factor = (54000/40000) = 1.35

3. PIPELINES

Weight adjustment factor = Quantity of chemical carried in pounds / 40,000
Quantity of chemical = (volume of pipeline * unit weight of the chemical carried)
Quantity = [3.14 * $(D-0.5)^2$ / 4 *144] [unit mile * 5280] [unit weight in pcf]
D = Diameter of the pipe in inches

4. WATERWAYS

Total quantity of hazardous material transported = 415715 tons
Total number of barges = 469
Weight carried by each barge = 415715/469 = 900 tons = 1800000 lbs
Weight adjustment factor = 1800000/40000 = 35

5. AIRPORTS

Average weight of jet engine oil carried = 600 lbs
Weight of hazardous material carried = W lbs
Weight adjustment factor = (600 + W)/40,000
W = 0
Weight adjustment factor = 0.015

Appendix 5
KRISP Technical Manual and User's Guide